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Technical Memorandum

PROGRAM REQUIREMENTS FOR TWO-MINUTE INTEGRATED DOPPLER SATELLITE NAVIGATION SOLUTION

Edited by J. B. MOFFETT

THE JOHNS HOPKINS UNIVERSITY ▪ APPLIED PHYSICS LABORATORY

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This report describes the algorithms used in computing a navigation fix from data provided by receivers of the two-minute integrated doppler type designed to operate with the Navy Navigation Satellite System. The theoretical basis for calculating the change in range from the navigator to the satellite as a function of the integrated satellite doppler shift data is developed. The original receiver of the integrated doppler type, the AN/SRN-9, is briefly described in its developmental versions, designed by APL, and its production versions, built by ITT. The Scripps/ONR 702CA receiver, built by Magnavox and used for oceanographic research applications of integrated doppler navigation, is also described.

The geometrical basis of the equations for obtaining a navigation fix is developed. The formatting and processing of the receiver data for the navigation solution are described preparatory to a presentation of step-by-step procedures for computing a three-variable navigation fix. Procedures for calculating satellite alerts, using data from the navigation solution, are also described. A representative FORTRAN program for obtaining a navigation fix and for calculating alerts is presented.

Information is also provided on scaling for the navigation fix computations, on the calculations for a four-variable (velocity north) navigation solution, on the procedures for applying a correction for tropospheric refraction, on a computer program for geodetic coordinate transformation, and on nonstandard numerical computation routines applicable to the navigation program.

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THE JOHNS HOPKINS UNIVERSITY • APPLIED PHYSICS LABORATORY
8621 Georgia Avenue, Silver Spring, Maryland 20910
Operating under Contract N00017-62-C-0604 with the Department of the Navy

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This report describes the algorithms used in computing a navigation fix from data provided by receivers of the 2-minute integrated doppler type designed to operate with the Navy Navigation Satellite System. The theoretical basis for calculating the change in range from the navigator to the satellite as a function of the integrated satellite doppler shift data is developed. The original receiver of the integrated doppler type, the AN/SRN-9, is briefly described in its developmental versions, designed by APL, and its production versions, built by ITT. The Scripps/ONR 702CA receiver, built by Magnavox and used for oceanographic research applications of integrated doppler navigation, is also described.

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Information is also provided on scaling for the navigation fix computations, on the calculations for a four-variable (velocity north) navigation solution, on the procedures for applying a correction for tropospheric refraction, on a computer program for geodetic coordinate transformation, and on nonstandard numerical computation routines applicable to the navigation program.

PREFACE

In support of the Naval Electronic Systems Command, the Applied Physics Laboratory is responsible for the development and evaluation of integrated doppler satellite navigation equipment and programs. In partial fulfillment of this responsibility, this report presents the computer program requirements for the 2-minute integrated doppler satellite navigation computations. The report is intended to provide all the information necessary for writing a digital computer program to obtain a position fix using data from the Navy Navigation Satellite System.

The information presented updates the program requirements given in TG 819-1 (Ref. 1) and, in addition, includes the on-line data processing procedures that are required before the calculation of a real-time navigation fix.

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1. NAVY NAVIGATION SATELLITE SYSTEM

The Satellite Navigation System developed by the Department of the Navy is a worldwide, all-weather navigation system that can provide a navigational fix at intervals of approximately 2 hours or less. The system is shown schematically in Fig. 1 and consists of near-earth satellites, tracking stations, injection stations, a computing center, and shipboard navigation equipment.

The system employs the doppler effect for both satellite position determination and navigation. In the former, four tracking stations in precisely known locations observe the doppler shift of the ultrastable radio signals generated by the satellite transmitter as the satellite approaches and recedes from the stations. This doppler information is translated into satellite positions as a function of time by the computing center. From this information and with the knowledge that the motion of the satellite is governed by Newton's laws of motion, the position of the satellite as a function of time can be predicted. These predictions become the ephemeris of the satellite for the predicted duration (16 hours) and are stored in the memory of the satellite by the injection station. As the satellite orbits the earth, it continually reads out data from which its position can be computed together with precision time. This transmission is continually updated by the satellite by discarding obsolete data and drawing more timely data from its memory. To determine his position, a navigator equipped with shipboard navigation equipment need only observe the doppler shift in the satellite signals, obtain the data on the satellite position, and perform the necessary computations. The navigator remains completely passive; i.e., no interrogation of the satellite is necessary.

The ground support system consists of tracking stations to receive, record, and digitize doppler signals

Fig. 1 NAVY NAVIGATION SATELLITE SYSTEM

from the satellites; a computing center where future orbits, orbital parameters, and time corrections are computed; and an injection station to transmit these new orbital parameters and time corrections to the satellite. In addition, the satellite time signals are compared with Universal Time. This information is used in the computing center for the time correction computations. The U. S. Navy Astronautics Group, with headquarters at Point Mugu, California, is responsible for operating the system.

Figure 2 shows a block diagram of the AN/SRN-9 system. The purpose of this report is to provide detailed information for the navigation solution and alert computations shown as part of the computer programming. The descriptions of the remainder of the system provided in this report are intended to provide background information only and are not a specification of any form.

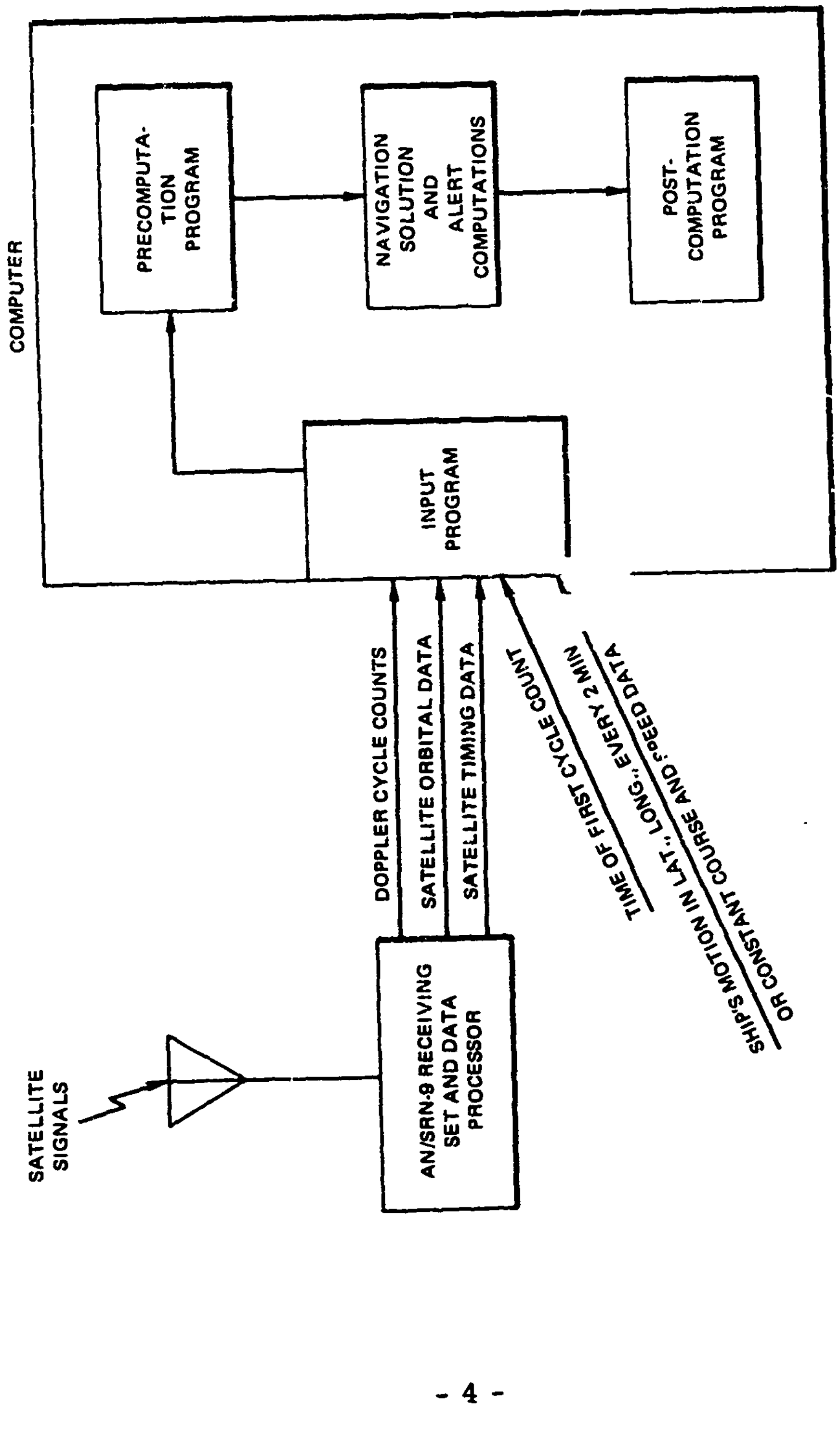


Fig. 2 BLOCK DIAGRAM OF AN/SRN-9 SYSTEM

2. INTEGRATED DOPPLER MEASUREMENT OF SLANT RANGE CHANGE

Integrated doppler navigation is based on the concept that the integral of the doppler shift of the satellite signal, as observed by the navigator, over a fixed time interval is a measure of the change in the slant range from the satellite to the navigator over this same interval (Fig. 3). The theory of the slant range change measurement is as follows:

A satellite signal transmitted at time t_k with slant range S_k will be received by the navigator at time $t_k + S_k/c$. If the satellite is transmitting a stable signal at frequency $(f_o-\bar{f})$ continuously between transmission of two time mark signals (transmitted at times t_k and t_{k-1}) the ground observer will count $(f_o-\bar{f})X\tau$ cycles for the interval between receipt of the time markers ($\tau = t_k - t_{k-1}$). The frequency of this received signal will be denoted $f_R(t)$ and the receiver reference frequency f_o. A difference frequency therefore exists in the ground receiver of frequency $f_o-f_R(t)$. The total number of cycles of this difference frequency between receipt of two satellite time marks is measured by counting positive zero-crossings between times $t_{k-1} + S_{k-1/c}$ and $t_k + S_{k/c}$. The apparent doppler count accumulation at a particular frequency (nominally f_o) between receipt of two such successive time marks is therefore:

$$N_k = \int_{t_{k-1}+\frac{S_{k-1}}{c}}^{t_k+\frac{S_k}{c}} (f_o - f_R(t))\,dt = f_o t \Bigg|_{t_{k-1}+\frac{S_{k-1}}{c}}^{t_k+\frac{S_k}{c}} - (f_o - \bar{f})\,\tau; \qquad (1)$$

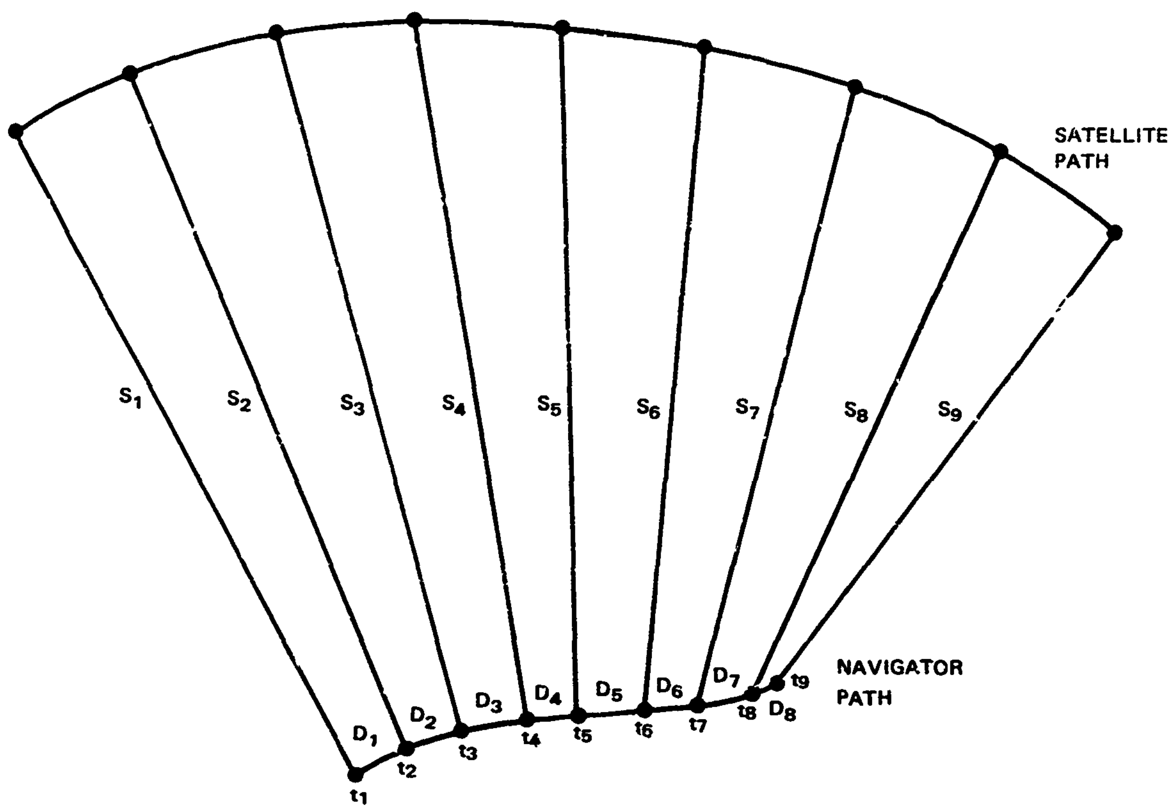


Fig. 3 SLANT RANGE MEASUREMENT

i.e., as noted,

$$\int_{T_{k-1}+\frac{S_{k-1}}{c}}^{t_k+\frac{S_k}{c}} f_R(t)\,dt = (f_o - \bar{f})\tau \tag{2}$$

where

$\tau = t_k - t_{k-1}$,

f_o = reference frequency,

$\bar{f}$ = constant satellite offset frequency, and

c = vacuum speed of light.

Therefore

$$N_k = \frac{f_o}{c}\,(S_k - S_{k-1}) + \bar{f}\,\tau, \tag{3}$$

from which the apparent slant range change over the k th interval is

$$S_k - S_{k-1} = \hat{S}_k = L_o N_k - \bar{f}\,L_o\,\tau, \tag{4}$$

where

$L_o = \frac{c}{f_o}$ = vacuum wavelength at reference frequency f_o.

The quantity $S_k - S_{k-1}$ would be an exact measurement of the slant range change if the process took place in a vacuum. The slant range change of Eq. (4) is the effective RF path length change in the refractive media through which the RF energy must pass to reach earth. Therefore, the doppler cycle count must be corrected for refraction to make it correspond more nearly to a vacuum doppler count.

Details of the correction for ionospheric refraction as implemented in the APL, International Telephone and Telegraph Company (ITT), and Magnavox equipment are given in Section 3.

3. INTEGRATED DOPPLER TRACKING EQUIPMENT

DEVELOPMENTAL AN/SRN-9 EQUIPMENT

In the early stages of the APL development of receiving equipment for use in the integrated doppler count method of navigation, the technical approach was centered around a single-frequency system. It was recognized that the use of a single-frequency system operating at the higher frequencies, i.e., 400 MHz, would result in a navigation error of approximately 1 nmi because of the refraction effect of the ionosphere. The elimination of the requirements for a 150-MHz phase-locked receiver, for a more complex antenna with dual preamplifiers, and for refraction correction equipment appeared desirable in terms of the resultant equipment simplification and lower cost. The single-frequency system was built in breadboard form at the Laboratory, and the feasibility of the system demonstrated in mid-1961. A block diagram of this system is shown in Fig. 4.

The design of a two-frequency system, shown in block diagram form in Fig. 5, was begun by the Laboratory about the same time the single-frequency system reached its breadboard stage. This design effort disclosed that since the two received frequencies are always in constant ratio within a few parts in 10^{-8} (the order of the refraction effect) the second receiver need not be a phase-locked receiver, but could be merely slaved to the 400-MHz phase-locked receiver. The two-frequency system design was developed and tested as an engineering model and subsequently developed into a prototype form designated XN-5. No further development of the single-frequency system was undertaken by the Laboratory.

Basic to the design of both systems is the stable oscillator. Any bias in measuring frequency that is maintained over a pass (as opposed to point-to-point noise within a pass) produces a proportional error in position. The assumption is made, therefore, that the frequency of the local oscillator is an unknown. This assumption requires

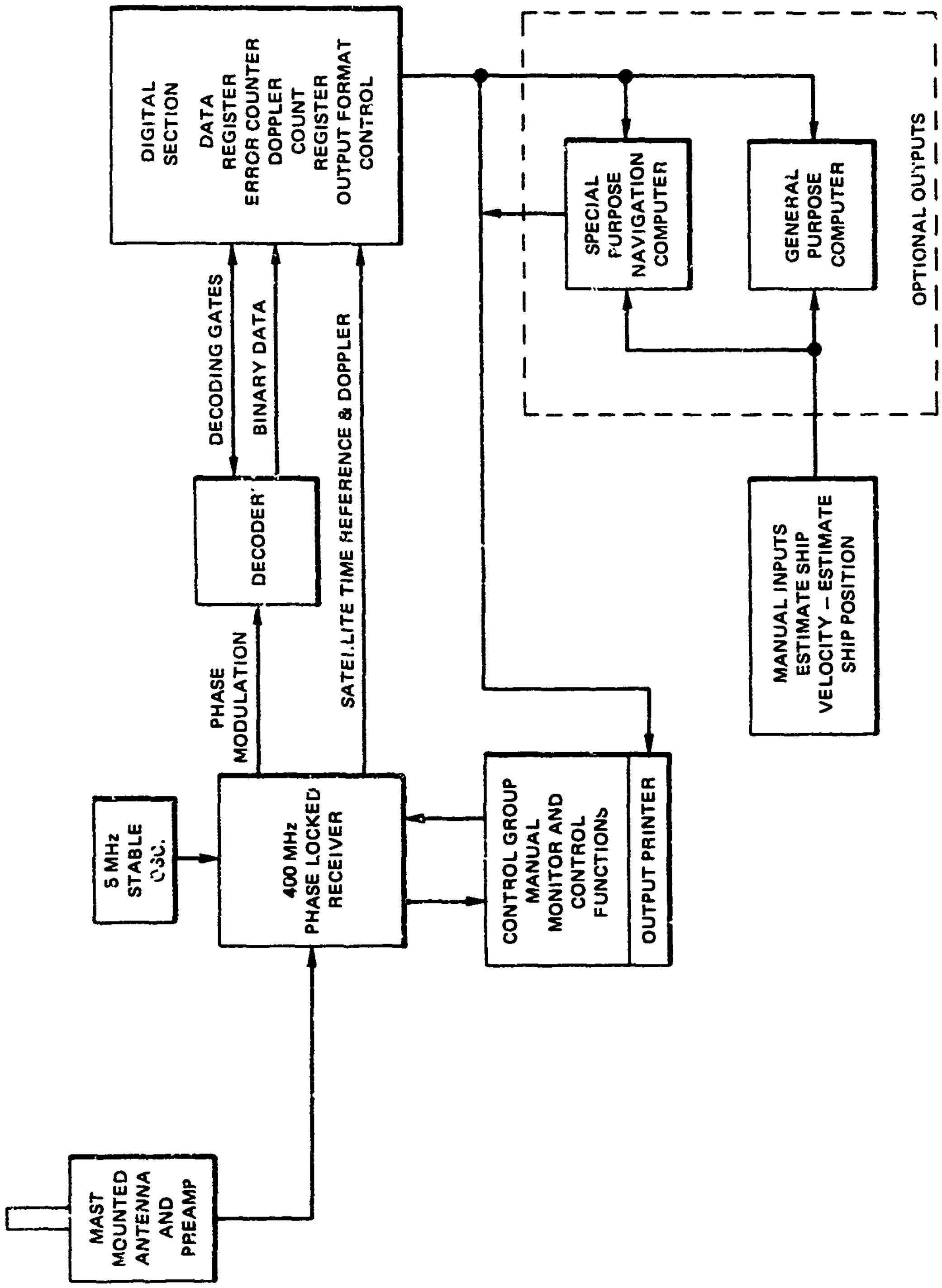


Fig. 4 BLOCK DIAGRAM OF SATELLITE INTEGRATED DOPPLER NAVIGATION EQUIPMENT, SINGLE-FREQUENCY SYSTEM

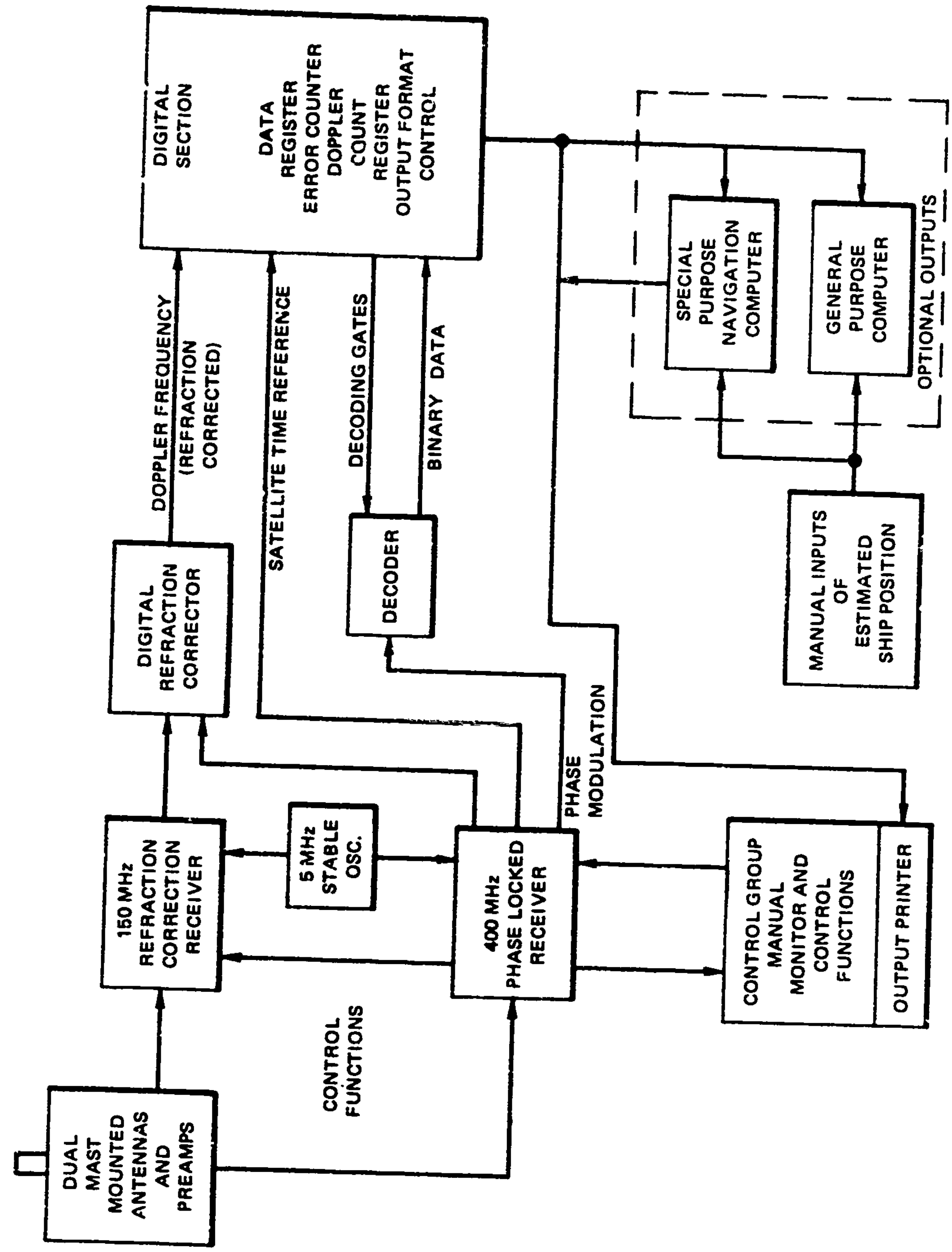


Fig. 5 BLOCK DIAGRAM OF SATELLITE INTEGRATED DOPPLER NAVIGATION EQUIPMENT, DUAL-FREQUENCY SYSTEM

that the measurements and computations needed for a navigation fix be arranged to eliminate the value of the frequency of the oscillator. When this elimination is done properly, the only stability required is five parts in 10^{11} over a 2-minute period. Such stability can be achieved, and a carefully chosen crystal in a thermostatically controlled oven with a large thermal time constant is entirely adequate.

The AN/SRN-9 (XN-5) receiving equipment has five basic elements: (1) the antenna and preamplifiers, (2) the receiver-demodulator, (3) the digital section, (4) the control group (output section), and (5) the 5-MHz oscillator (Fig. 6).

The antenna is a whip over a ground-plane mounted on the superstructure of the ship, along with preamplifiers for the 150- and 400-MHz signals.

The receiver-demodulator contains circuitry to perform the following functions:

1. Selectively track a satellite signal after manual lock-on.

2. Demodulate the binary data from the carriers. Figure 7 shows the binary modulation format.

3. Provide timing signals to the digital section at the doublet (half bit) rate (one every 9.83 ms) as derived from the doublet coding in the satellite messages.

4. Produce a sequence of pulses from which a refraction corrected doppler count is obtained.

These functions are described in detail on the following pages.

The higher frequency signal transmitted from the satellite is 400 MHz - f_H, where $f_H \approx 32$ kHz, since the

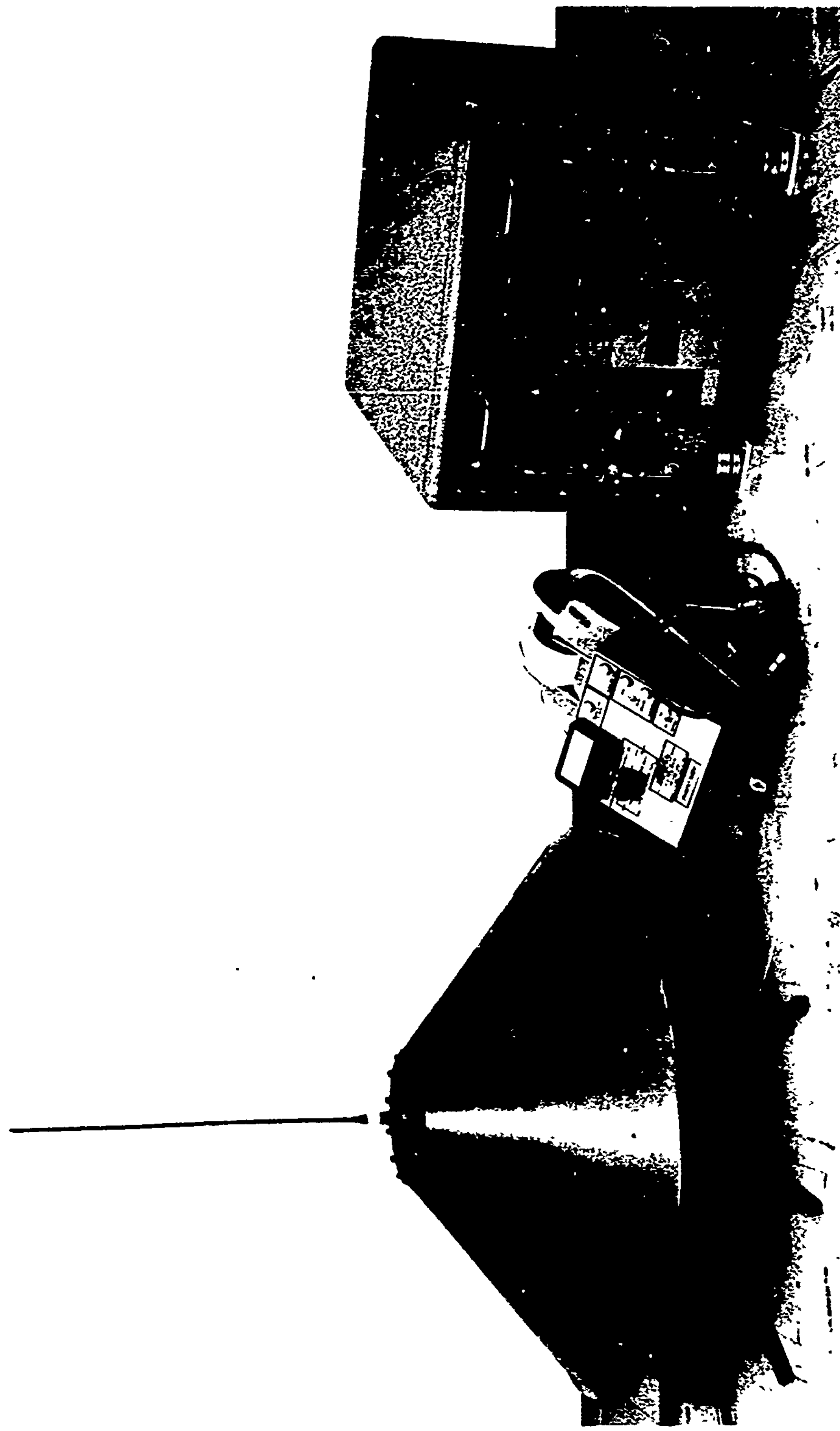
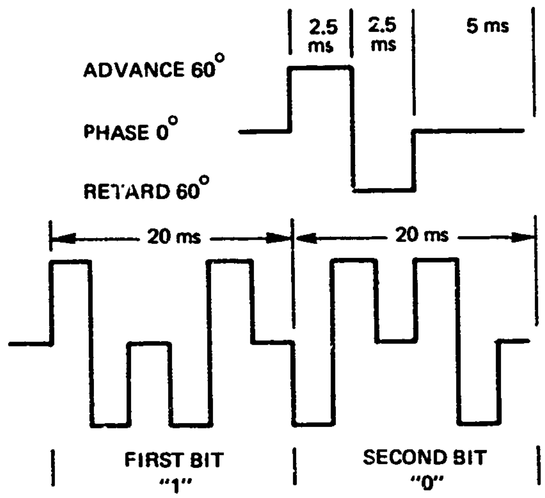


Fig. 6 AN/SRN (XN-5) RECEIVING EQUIPMENT



THE PHASE OF THE DOPPLER SIGNAL IS ADVANCED AND THEN RETARDED TO REPRESENT ONE POLARITY, RETARDED AND THEN ADVANCED FOR THE REVERSE POLARITY. EACH HALF BIT IS TRANSMITTED TWICE, THE SECOND TIME IN REVERSE POLARITY.

"1" = ADVANCE–RETARD–SPACE
RETARD–ADVANCE–SPACE

"0" = RETARD–ADVANCE–SPACE
ADVANCE–RETARD–SPACE

BIT RATE ≅ 50/S

Fig. 7 COMMUNICATION LINK MODULATION WAVEFORMS

frequency offset is nominally 80 ppm. This signal is shifted d_H because of the doppler effect and ϵ_H because of ionospheric refraction. For the system parameters used d_H is between ±10 kHz and ϵ_H is between ±3 Hz. The set receives a signal from the satellite on a whip antenna at a frequency of 400 MHz - $f_H + d_H + \epsilon_H$. This signal is amplified in a 400-MHz automatic gain controlled (AGC) preamplifier with a maximum gain of 70 dB, a bandwidth of 1 MHz, and a noise figure of 10 dB.

The signal from the preamplifier then is mixed with a local RF reference signal. The resulting 5-MHz difference frequency is amplified in a high gain, 3-kHz bandwidth 5-MHz IF amplifier.

The IF output is fed in parallel to two phase comparators in which it is compared with the phase of quadrature components of a stable 5-MHz reference signal.

The phase comparator produces a DC voltage that is used to detect phase or frequency errors in the RF frequency and control a second order frequency/phase loop, which maintains the frequency and phase relationship between the RF reference signal and the received signal.

The stable 5-MHz reference oscillator uses design concepts similar to those used in the satellite oscillator, i.e., a thermostatically controlled oven with a very long thermal time constant between the oven and a monel slug, which contains the critical circuits. Since the vacuum of space is not available for the earthbound oscillator, a great amount of thermal insulation is used, resulting in a relatively large physical size.

The 5-MHz stable reference frequency is multiplied by a factor of 81 to 405 MHz. The difference between this frequency and the locally generated RF reference signal is, provided the phase-locked loop is tracking a signal, the amount by which the received signal is below 400 MHz, i.e., $f_H - d_H - \epsilon_H$. A pulse generator converts the doppler cycles from the doppler mixer into pulses.

The 150-MHz receiver is slaved to the 400-MHz receiver to "listen" to a very narrow 20-Hz bandwidth portion of the RF spectrum centered at a "predicted" frequency exactly 3/8 of the frequency tracked by the 400 MHz phase-locked receiver. The slaved receiver produces two signals at the difference frequency between the predicted frequency and the 150-MHz signal received. The relative phase of these signals indicates whether the 150-MHz signal is above or below 3/8 of the high frequency signal.

The satellite transmits as its lower frequency 150 MHz - f_L (where $f_L \approx 12$ kHz), i.e., 3/8 of the high frequency transmitted. This signal is shifted by doppler and ionospheric effects to a received frequency of 150 MHz - $f_L + d_L + \epsilon_L$. The doppler shift is proportional to frequency, but the ionospheric refraction shift has been found to be inversely proportional to frequency. The received frequency may then be expressed as,

$$150 \text{ MHz} + 3/8\,(-f_H + d_H) + 8/3\,\epsilon_H.$$

A local reference signal at 3/8 of the high frequency local reference signal is mixed with the amplified low frequency signal with the following results:

$$\begin{aligned} &3/8\,[405 \text{ MHz} - f_H + d_H + \epsilon_H] - [150 \text{ MHz} + 3/8\,(-f_H + d_H) + \\ &8/3\,\epsilon_H] = 1.875 \text{ MHz} + [3/8 - 8/3]\,\epsilon_H = \\ &1.875 \text{ MHz} - 55/24\,\epsilon_H . \end{aligned} \tag{5}$$

Because $55/24\,\epsilon_H$ is typically less than 5 Hz, this signal can be amplified in a very narrow 20-Hz bandwidth IF amplifier. AGC detection may safely be performed in this narrow bandwidth.

The phase relationship of this RF output and the stable reference oscillator determines whether the refraction

correction adds or deletes cycles from the doppler count. The corrected doppler pulse train is then counted in the doppler accumulator to measure satellite slant range change during the count interval.

The 400-MHz phase comparator also produces a signal whose voltage excursions versus time are an accurate representation of the phase excursions of the input signal [illegible] in Fig. 8. The decoder accepts these doublet data fr[illegible] phase comparator, synchronously detects them, [illegible]rts them to a binary format compatible with the [illegible]ection. The synchronous detection is followed by an integration with end-of-bit sampling to afford maximum immunity from noise errors. The properly timed gating signals required for synchronous decoding are derived from the digital section.

The decoder thus associates the adjacent doublets in the received signals with appropriate binary bits. The process is initiated with an arbitrary association of adjacent doublets. The resulting binary bits are observed in the digital section, and pulses generated by the pairing of doublets are counted. If the count exceeds a specified threshold the doublet association is reversed, and the correct pairing of doublets into binary bits is achieved. Binary data are sent serially from the receiver-demodulator into the digital unit.

A precise timing signal based upon the message modulation rate is derived in an internal clock in the receiving equipment. This synchronized internal clock controls the decoding, printing, and doppler count gating operations with an accuracy of better than 0.2 ms. Because the operational satellites transmit the end of message word two at each Universal 2-minute Time ±500 μs, adequate time information is obtained from the satellite for navigation and doppler gating.

The digital section contains shift registers for accumulating the doppler count and for storing the serial binary data decoded from the satellite messages.

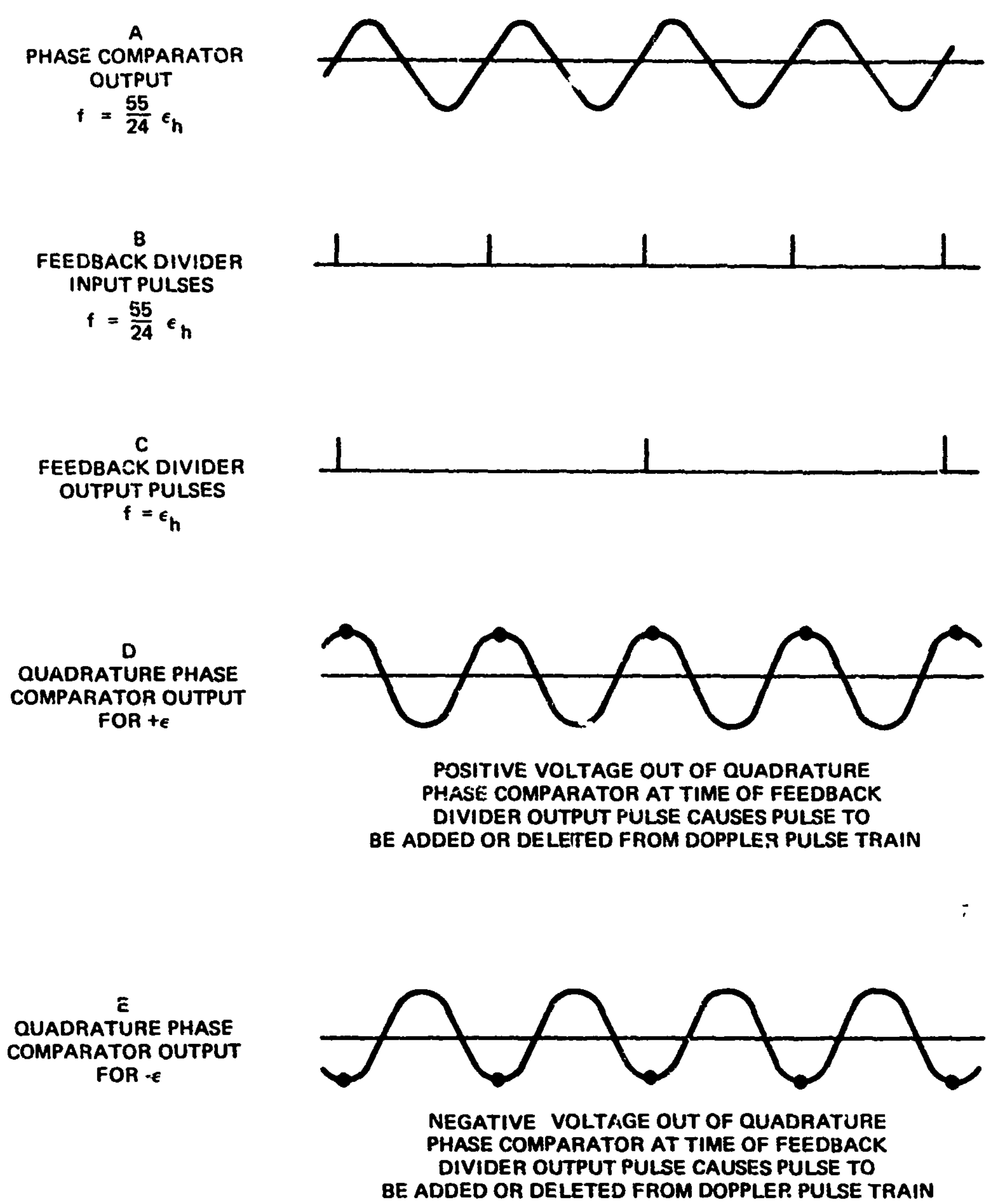


Fig. 8 AN/SRN-9 (XN-5) REFRACTION CHANNEL WAVEFORMS

The digital section also contains an output register and the necessary counting and control logic to organize the satellite messages into words and digits (output format control). It also programs the data and other timing signals to the output terminals. The message data are extracted in four-bit groups (i.e., excess-three binary coded decimal format). Control signals are available to take all data (every word) or select only every sixth word (all that is necessary) for normal navigation.

The data used by the integrated doppler navigator are contained in words 8, 14, 20, 26, etc., up to 128. These words include the satellite orbit parameters; the output format control selects these words and prints them out on a paper tape along with the integrated doppler count.

The control group of the receiving equipment in its simplest form produces a printed tape listing:

1. Between three and eight accumulated refraction corrected doppler counts, each for a 2-minute period and with end points precisely governed by satellite-transmitted Universal Time 2-minute marks.

2. Between three and eight readouts of the satellite-stored orbit parameters, defining satellite positions every 2 minutes.

All equipment control functions are provided by a control group packaged with the numerical printer. Figure 9 shows one control group-printer configuration. The printer in this configuration prints eight of the nine digits of the satellite word. Other later control group configurations print all nine digits.

From the control group, the navigator can monitor the operation of the equipment. In operation, the navigator remotely tunes the 400-MHz receiver from whence it obtains all necessary control functions.

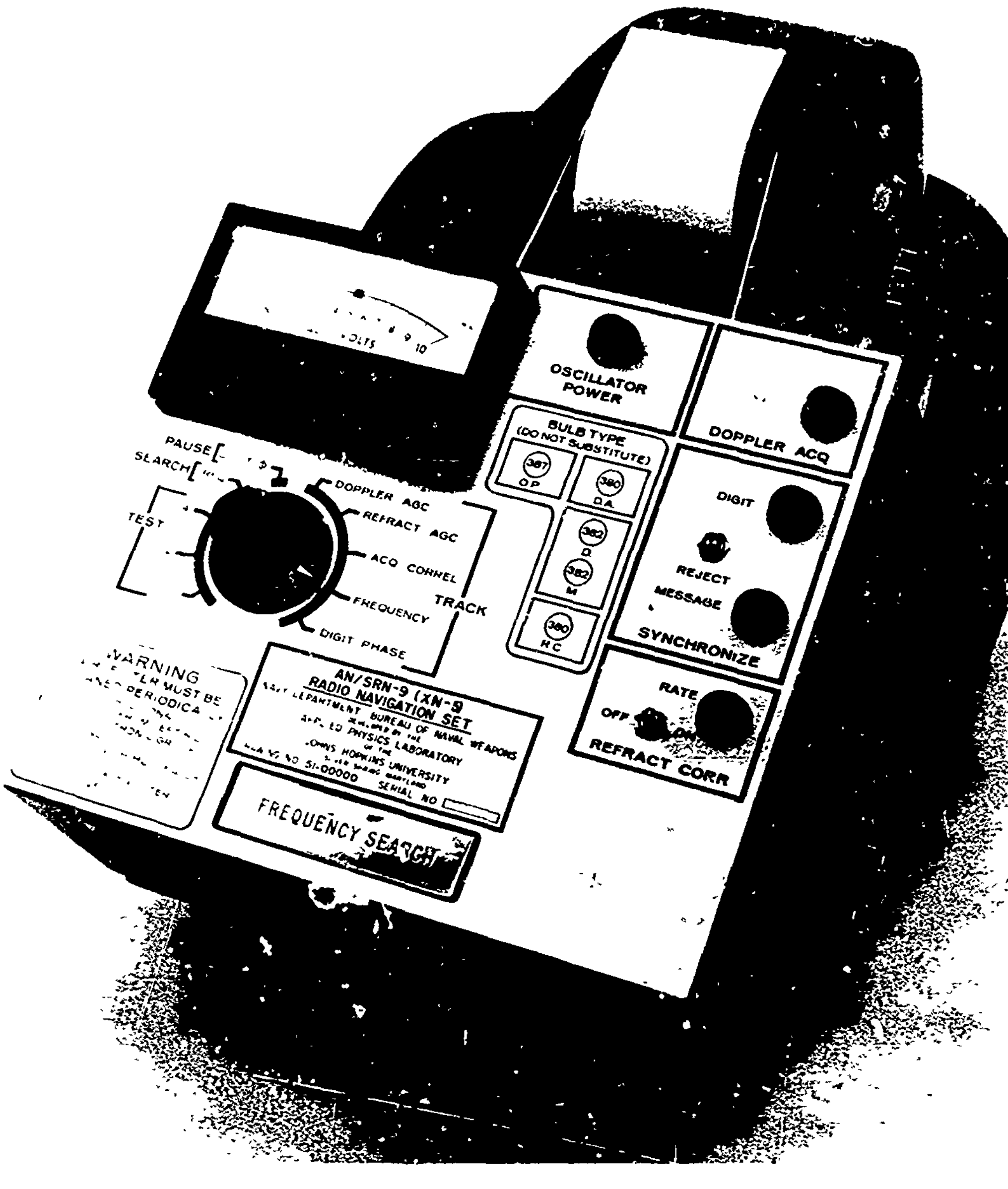


Fig. 9 AN/SRN–9 (XN-5) CONTROL GROUP-PRINTER CONFIGURATION

A sample of the nine digit printer output is shown in Fig. 10. The first line is one value of the total refraction corrected cycle count for the previous 2 minutes. The second line is the orbital information for the epoch 6 minutes before the beginning of the 2-minute interval, followed by the orbital information for the epoch 4 minutes before, and so on through the information for the epoch 8 minutes after the end of the 2-minute interval. After these 8 lines, there occur 17 lines of data from the fixed portion of the satellite memory. Following these lines of data there is another reading of the doppler counter. This reading is readily distinguished from the orbital data by the different number of digits in the line. The shifting of the ephemeral or variable portion of the memory can be observed by noting the next 8 lines of the printout. The single and double signs at the beginning of the fixed and ephemeral readout are a code that is described in Section 5.

In summary, for any satellite pass the following sequence of events will occur in the receiving equipment:

1. The receiver-demodulator is manually locked onto the satellite signals and phase tracks during the satellite pass.

2. The receiver-demodulator begins decoding the binary data based on an arbitrary association of adjacent doublets.

3. The digital section monitors the decoded data and properly pairs the demodulated doublets to form binary bits. When the proper pairing is achieved, the digital section energizes the bit synchronization line.

4. The counting and control logic is reset by the synchronization word in the satellite data format. The first time the synchronization word is received after bit synchronization, the digital section outputs a synchronization pulse. A 2-minute Universal Time pulse is also generated each time the synchronization sequence

```
   2993770 ←—— DOPPLER CYCLE COUNT
++140241337
++000370950
++010460566
++020520170    EPHEMERAL MEMORY READOUT
+-030520205
+-040430510
+-050390743
+-060270900
++110391920
+  36488020
+  04278850
+  00196610
+  00187520
+  07465340
+  23720880
+  00000080    FIXED MEMORY READOUT
-  00005880
+  32350310
+  20189280
+  54903120
+  10000000
--199870000
++000000000
++000000000
++000000000
   3373172 ←—— DOPPLER CYCLE COUNT
++000370950
++010460566
++020520170
+-030520205    EPHEMERAL READOUT
+-040480510
+-050390743
+-060270900
+-070120961
++110391920
+  36488020
+  04278850
+  00196610
+  00187520
+  07465340
+  23720880
+  00000080
-  00005880    FIXED MEMORY READOUT
+  32350310
+  20189280
+  54903120
+  10000000
--199870000
++000000000
++000000000
++000000000
   4093892 ←—— DOPPLER CYCLE COUNT
```

Fig. 10 AN/SRN-9 (XN-5) DOPPLER AND ORBITAL PARAMETER NINE-DIGIT PRINTOUT

(0111111111111111111111110)

is received.

5. The counting and format control logic in the digital section governs the handling of the binary data from the satellite and the accumulation and output of the doppler count.

6. The 2-minute doppler count and satellite message data are printed out in decimal form on the control group printer.

7. Whenever an interrupt in the satellite signal occurs, bit synchronization must be reestablished.

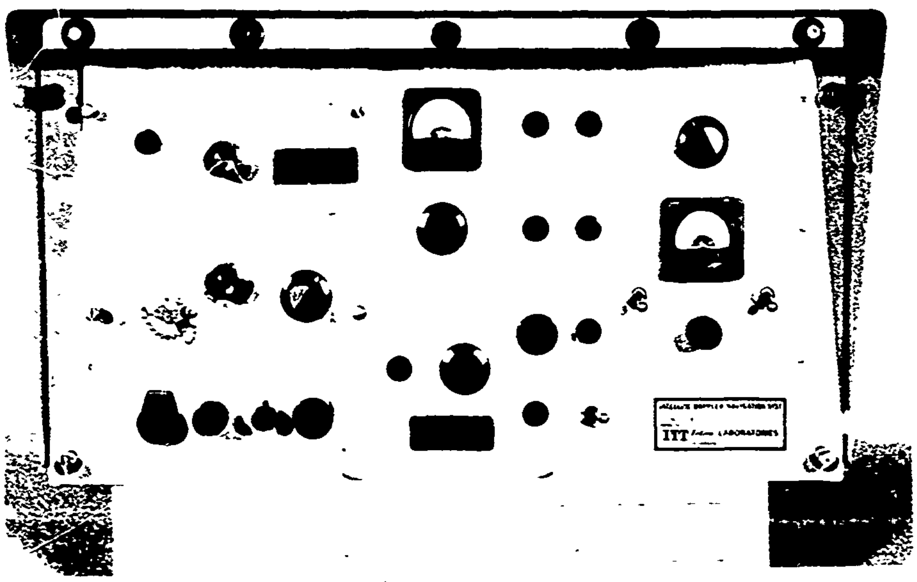
Reference 2 is a detailed description of the AN/SRN-9 (XN-5) Radio Navigation Set.

RADIO NAVIGATION SETS AN/SRN-9 AND AN/SRN-9A

Under contract to the Naval Ship Systems Command, ITT has produced shipboard navigation equipment designated RadioNavigation Sets AN/SRN-9 and AN/SRN-9A to the specifications SHIPS-R-5111 (Ref. 3), SHIPS-R-5111A (Ref. 4), and SHIPS-R-5111B (Ref. 5). These specifications embody APL experience with the developmental AN/SRN-9 equipment. Radio Navigation Set AN/SRN-9 is shown in Fig. 11 and described in Ref. 6. Radio Navigation Set AN/SRN-9A is shown in Fig. 12 and described in Ref. 7. Reference 8 describes operational procedures for both sets when used with the CP-967/UYK computer.

The two sets differ in that the AN/SRN-9A has automatic signal acquisition and coast mode features (explained below); in addition, doppler data may be obtained over either 2-minute intervals or approximately 4.6-second intervals at operator option. The following sections will apply only to 2-minute interval data inasmuch as programming procedures for 4.6-s interval (or short count) data are beyond the scope of this report.

(a) ANTENNA



(b) RECEIVER

Fig. 11 AN/SRN–9 RADIO NAVIGATION SET

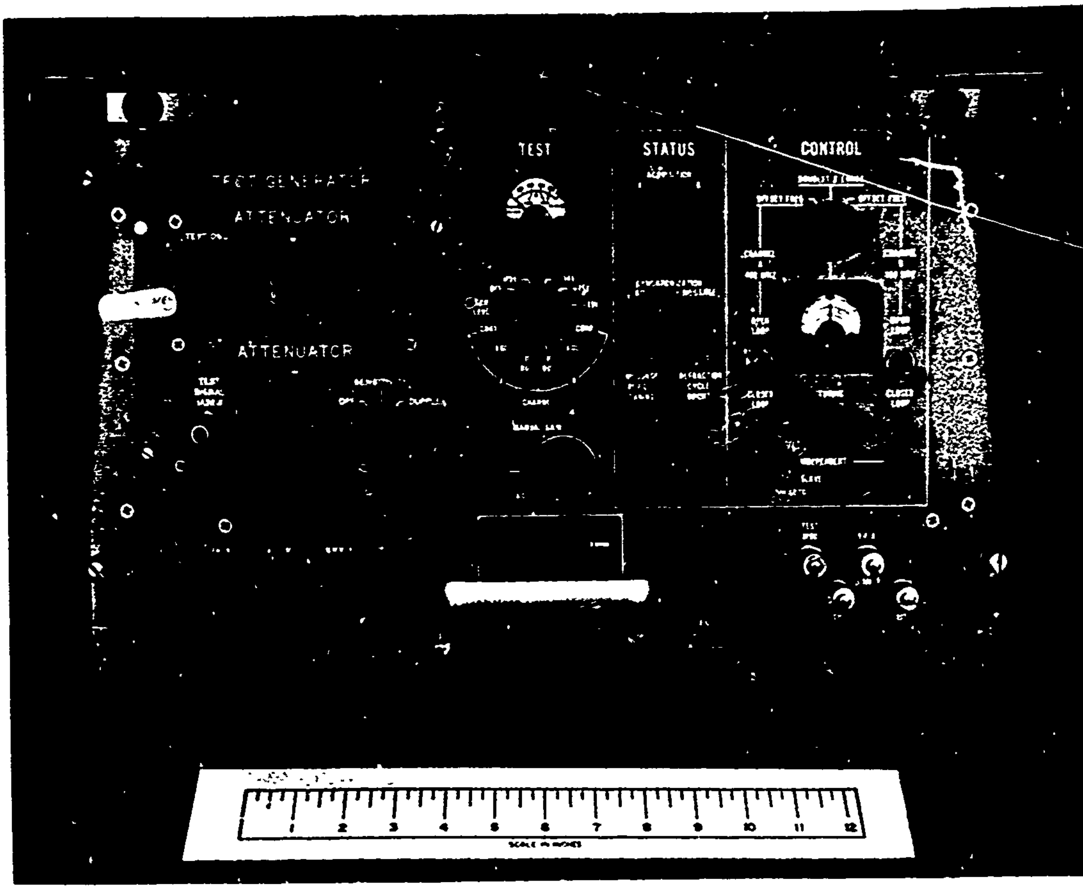


Fig. 12 AN/SRN–9A RADIO NAVIGATION SET

In the AN/SRN-9 set, loss of lock during a 2-minute interval results in loss of all data for that interval. If the AN/SRN-9A set loses lock during a 2-minute interval, however, the coast mode feature allows satellite message data to be obtained upon signal reacquisition, provided the time between loss of lock and reacquisition does not exceed 60 seconds. In addition varying combinations of doppler, refraction, and satellite message data are obtainable in a loss of lock situation, depending upon whether it is the 150 MHz, 400 MHz, or both signals that are lost. The following tabulation shows all the consequences for the various combinations:

Condition	Doppler Data	Refraction Data	Message Data
Unlocked	-	-	-
Both channels locked during first transfers (initial message sync.) (1)	BCDX3"0"	BCDX3"0"	BCDX3
Both channels locked	BCDX3	BCDX3	BCDX3
400 MHz locked 150 MHz unlocked	BCDX3	BCDX3"0"	BCDX3
400 MHz unlocked 150 MHz locked	BCDX3"0"	BCDX3"0"	BCDX3
Coast Mode (2)	Binary "0"	Binary "0"	Binary "0"

Note (1) BCDX3 denotes valid data format.
(2) During coast mode, binary "0" will be outputted to computer.

From the standpoint of programming a computer for use with data obtained with either the AN/SRN-9 or AN/SRN-9A Radio Navigation Set, the differences between these equipments and the developmental AN/SRN-9 equipment described in the previous section lie in the treatment of the ionospheric refraction correction and in the formatting of the output data. Whereas the refraction correction circuitry

in the developmental equipment adds or deletes cycles from the doppler count such that a refraction corrected doppler count is obtained for use in navigation computations, the AN/SRN-9 and AN/SRN-9A equipment is designed to present the refraction information separately from the doppler count, and the requisite correction must be done during subsequent computations. The refraction count data in the AN/SRN-9 and AN/SRN-9A equipment take on values between 1000 and 3000 and are scaled such that a count of 2000 is an indication that no correction is required or (in the AN/SRN-9 only) that the refraction count is invalid.

The refraction correction equation to be implemented then is

$$N_k = N_{k_{400}} - \frac{24}{55} (R_k - 2000) \tag{6}$$

where

N_k = ionospheric refraction corrected doppler count,

$N_{k_{400}}$ = 400-MHz doppler count from ITT equipment, and

R_k = refraction count from ITT equipment.

The ITT equipment may be configured to output its data into a readout device, such as a printer or a paper tape punch, for later off-line calculation, or directly into a computer for real-time navigation. Figure 13 shows a thermal printer readout that could have been obtained from either an AN/SRN-9 or an AN/SRN-9A, for comparison with Fig. 10. Specific details of the format of the output data from the ITT equipment are described in the Data Types and Formats Section.

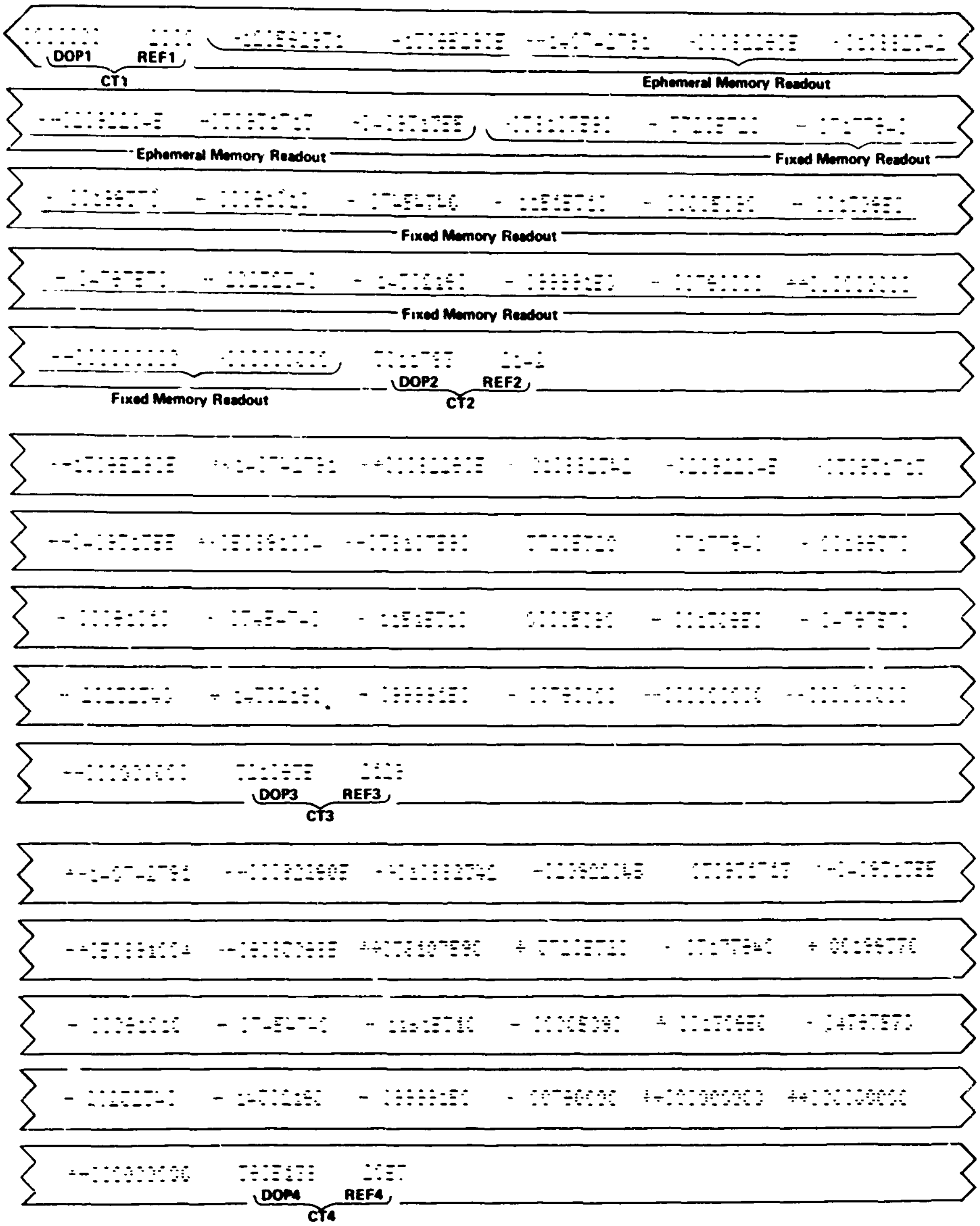


Fig. 13 AN/SRN-9 OR AN/SRN-9A TWO-MINUTE DOPPLER, REFRACTION, AND ORBITAL PARAMETER PRINTOUT

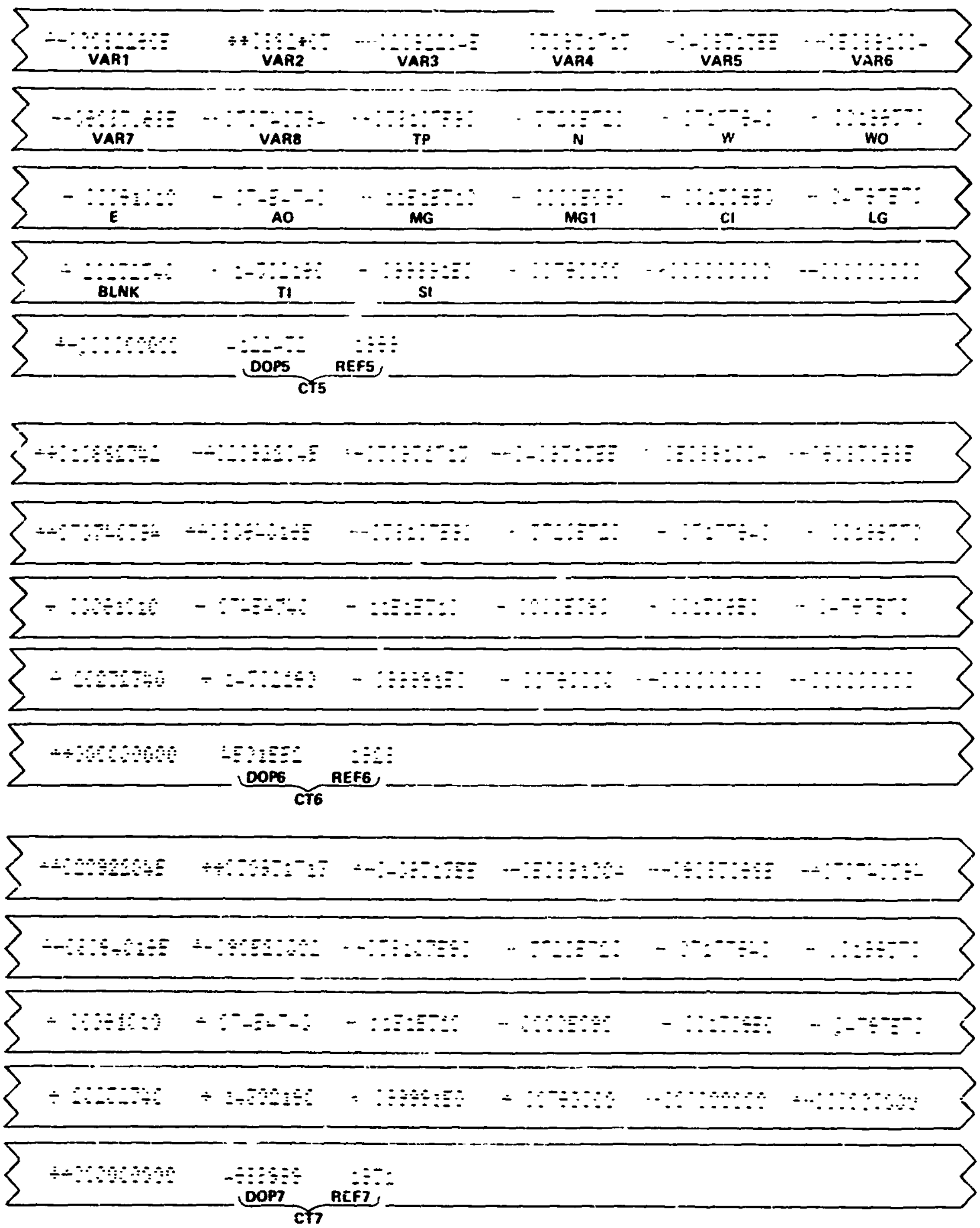


Fig. 13 AN/SRN-9 OR AN/SRN-9A TWO-MINUTE DOPPLER, REFRACTION, AND ORBITAL PARAMETER PRINTOUT (cont'd)

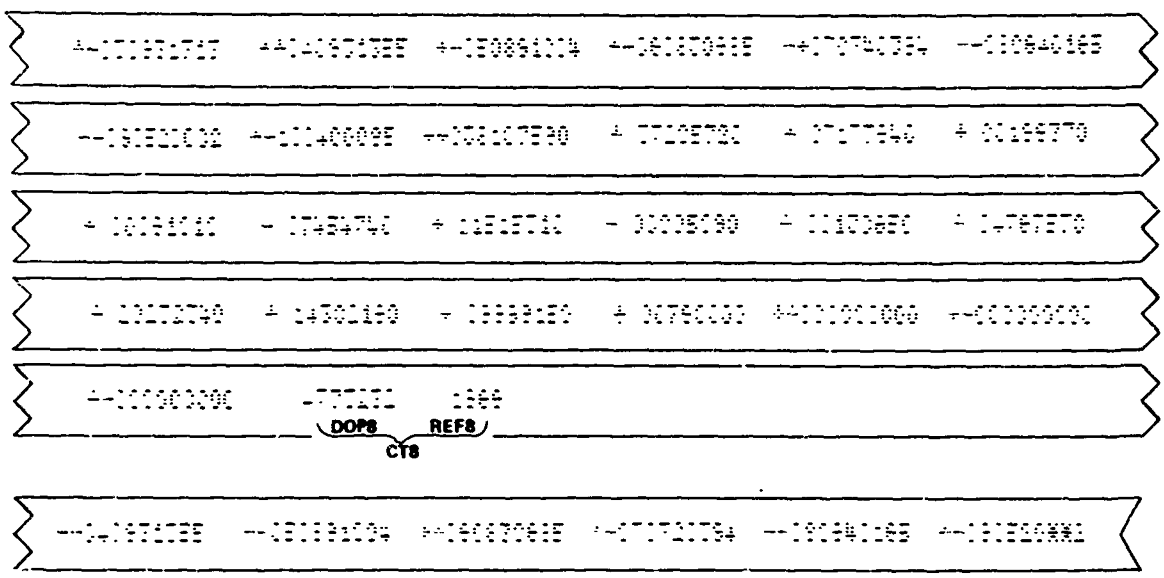


Fig. 13 AN/SRN-9 OR AN/SRN-9A TWO-MINUTE DOPPLER, REFRACTION, AND ORBITAL PARAMETER PRINTOUT (cont'd)

NAVIGATION SATELLITE RECEIVER SET 702CA

Under the sponsorship of the Office of Naval Research, the Scripps Institution of Oceanography of the University of California has contracted with the Magnavox Company for the Navigation Satellite Receiver Set 702CA, produced in accordance with Scripps Specification 0A0088 (Ref. 9). This specification also embodies APL experience with developmental integrated doppler navigation equipment. Figure 14 shows the equipment; Ref. 10 describes its operation and maintenance.

From the standpoint of programming a computer for use with the Navigation Satellite Receiver Set 702CA, the differences between this equipment and the developmental AN/SRN-9 equipment described previously lie in the treatment of the ionospheric refraction correction and in the formatting of the output data. Like the ITT AN/SRN-9 equipment the 702CA equipment also provides separate outputs for use in later calculations to obtain a refraction corrected doppler count. The 702CA outputs, however, are a 400-MHz doppler count and a 150-MHz doppler count scaled by the receiver to 400 MHz.

The refraction correction equation for Magnavox 702CA data is then

$$N_k = N_{k_{400}} + \frac{9}{55} (N_{k_{400}} - N_{k_{150}}) \qquad (7)$$

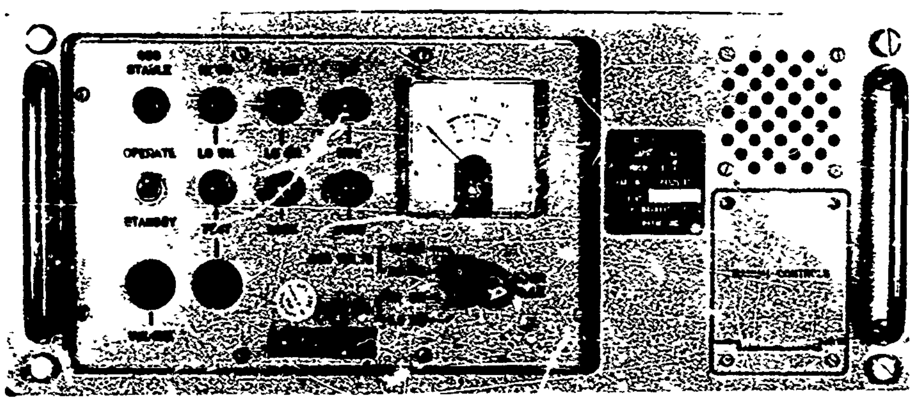
where

N_k = ionospheric refraction corrected doppler count,

$N_{k_{400}}$ = 400-MHz doppler count, and

$N_{k_{150}}$ = 150-MHz doppler count.

(a) ANTENNA



(b) RECEIVER

Fig. 14 NAVIGATION SATELLITE SET 702 CA

Figure 15 shows a printout obtained from the 702CA receiver on the HP 2115A computer for comparison with Fig. 10 (AN/SRN-9 (XN-5) printout) and Fig. 13 (ITT AN/SRN-9 or AN/SRN-9A printout). Note that the coding in the form of single and double signs shown in Figs. 10 and 13 is expressed in Fig. 15 as a digital coding. Specific details of the format of the output data from the Magnavox equipment are described later in the Data Types and Formats Section.

```
000000000 003023322
430732990 440812742 000872531 010912255
020931942 030921605 040891252 050830915
414088460 837170670 810687490 800197580
800061330 807455250 815310080 900004850
800125170 809053730 82023024  851300660
809999220 800510000 000000000 000000000
000000000 400 MHz DOPPLER   150 MHz DOPPLER

003263772 003263945
440812745 000872531 010912255 020931942  EPHEMERAL MEMORY READOUT
030921605 040891252 050830915 060750602
414088460 837170670 810687490 800197580
800061330 807455250 815310080 900004850
800125170 809053730 820230240 851800660  FIXED MEMORY READOUT
809999220 800510000 000000000 000200000
000000000

003737842 003737907
000872531 010912255 020931942 030921605
040891252 050830915 060750602 070640345
414088460 837170670 810687490 800197580
800061330 807455250 815310080 900004850
800125170 809053730 820230240 851800660
809999220 800510000 000000000 000000000
000000000
```

Fig. 15 702CA DOPPLER, REFRACTION, AND ORBITAL PARAMETER PRINTOUT AS OBTAINED ON HP2115A COMPUTER

4. GEOMETRICAL BASIS OF NAVIGATION EQUATIONS

The derivation of the equations used in the navigation solution as presented here is divided into two parts. The first of these parts will show the method of coordinate system transformation, which is used to obtain the navigator and satellite positions in a common coordinate system. The second part will show the derivation of satellite and navigator positions from basic information available to the navigator.

COORDINATE TRANSFORMATIONS

To show the derivation of the coordinate system transformations used in the navigation solution, first define a right-hand, earth-centered, inertial cartesian coordinate system XYZ which is oriented such that (1) its center is at the center of the earth, (2) its X-Y plane is coincident with the equatorial plane of the earth, (3) its Z-axis is coincident with the spin axis of the earth (the positive Z-axis points toward the north pole), and (4) its X-axis is coincident with the vernal equinox (First Line of Aries).

In a similar manner, define a right-hand, earth-centered coordinate system which is fixed with respect to the rotating earth. This system, denoted xyz, is oriented such that (1) its center is at the center of the earth, (2) its x-y plane is coincident with the equatorial plane of the earth, (3) its z-axis coincides with the spin axis of the earth, and (4) its x-axis is coincident with the plane of the Greenwich Meridian.

It can be easily visualized that, since the xyz coordinate system rotates with the earth, any fixed point on the earth will remain fixed with respect to the xyz system. This coordinate system would then be desirable as a reference system for the navigator, since his position at any

time may be represented as a point in the xyz system and, if he is not moving, his position within the coordinate system will not change with time.

Now define the angle between a line through the Greenwich Meridian on the x-y plane and the vernal equinox (First Line of Aries) as Λ_G. This angle is called the hour angle or Right Ascension of Greenwich. Pictorially, the XYZ and xyz coordinate systems appear as in Fig. 16. The transformation from XYZ to xyz coordinates is given by

$$
\begin{aligned}
x &= X \cos \Lambda_G + Y \sin \Lambda_G \\
y &= -X \sin \Lambda_G + Y \cos \Lambda_G \\
z &= Z \ .
\end{aligned}
\tag{8}
$$

Now define a three-dimensional coordinate system x'y'z' whose center is at the center of the earth and whose x'-axis lies in the equatorial plane of the XYZ coordinate system. The x' and y' directions in this coordinate system define a plane which is the orbital plane of the satellite. Further, define the inclination angle, i, of the satellite plane as the angle between the y'-axis and the equatorial plane, XY, and the angle Ω_o, the right ascension of the ascending node, as the angle between the x'-axis of the orbital plane and the X-axis of the XYZ coordinate system. The orientation of the orbital plane is shown in Fig. 17.

From examination of the geometry of the XYZ coordinate system and the x'y' plane, the transformation from the x'y' plane to the XYZ coordinate system is given by

$$
\begin{aligned}
X &= x' \cos \Omega_o - y' \cos i \sin \Omega_o \\
Y &= x' \sin \Omega_o + y \cos i \cos \Omega_o \\
Z &= y' \sin i \ .
\end{aligned}
\tag{9a}
$$

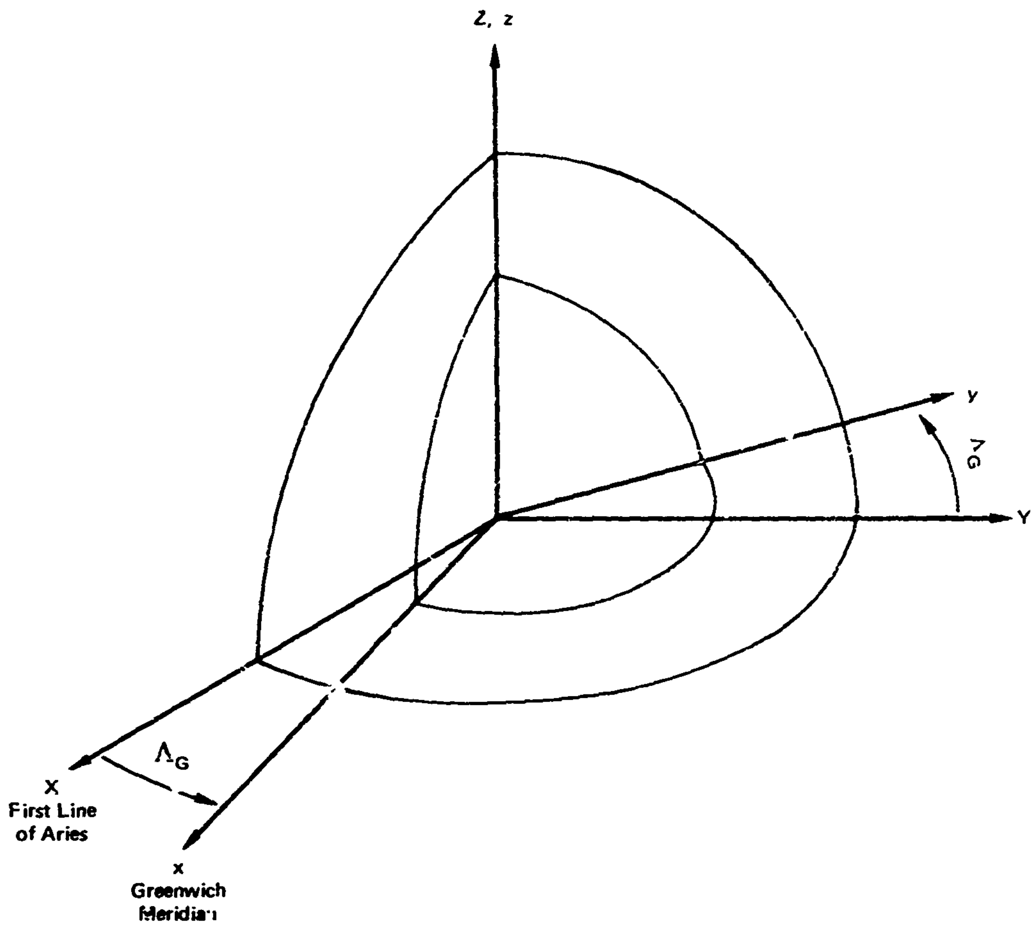


Fig. 16 XYZ AND xyz COORDINATE SYSTEMS

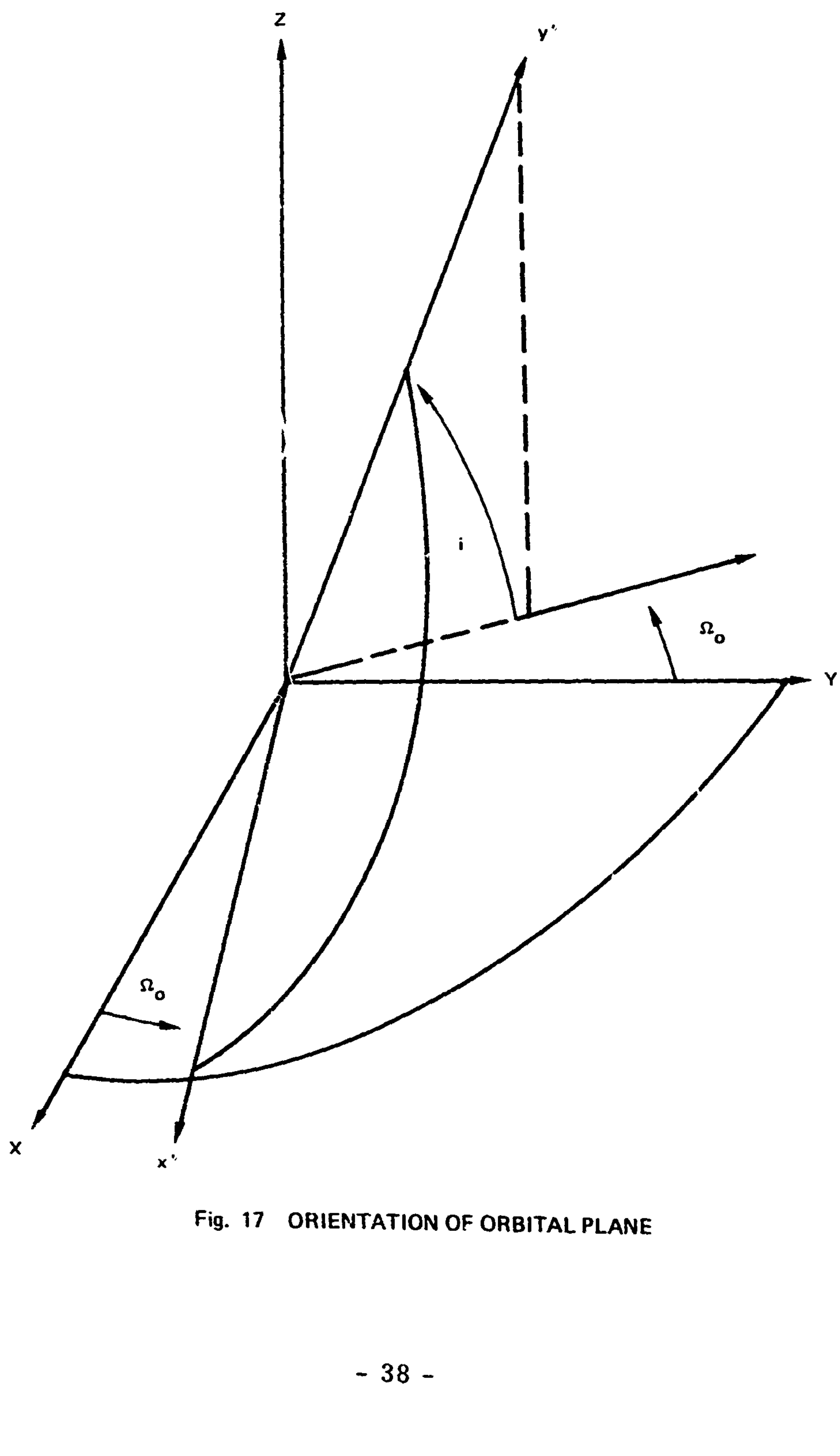


Fig. 17 ORIENTATION OF ORBITAL PLANE

Although the primary motion of the satellite will be in the x'y' plane, allowance will be made at this point for motion that is perpendicular to the plane of the satellite orbit. This direction will be defined as the z' direction and will be pointed such that the positive z'-axis forms a right-hand coordinate system with the x'y' plane. Figure 18 shows this x'y'z' coordinate system. The transformation to XYZ coordinates is given by

$$\begin{aligned} X &= x' \cos \Omega_o - y' \cos i \sin \Omega_o + z' \sin i \sin \Omega_o \\ Y &= x' \sin \Omega_o + y' \cos i \cos \Omega_o - z' \sin i \cos \Omega_o \\ Z &= y' \sin i + z' \cos i . \end{aligned} \tag{9b}$$

Now define the angle β to be the angle between the plane of the satellite orbit and the plane of the Greenwich Meridian. This difference is given by

$$\beta = \Omega_o - \Lambda_G . \tag{10}$$

By using the angle β it is now possible to transform the satellite orbital x'y'z' coordinate system directly into the navigator's xyz coordinate system without performing the initial transformation to XYZ coordinates. This transformation is of prime importance since it is the navigator's xyz coordinate system that will be used as the common coordinate system for the navigation solution computations. The transformation is given as follows:

$$\begin{aligned} x &= x' \cos \beta - y' \cos i \sin \beta + z' \sin i \sin \beta \\ y &= x' \sin \beta + y' \cos i \cos \beta \quad z' \sin i \cos \beta \\ z &= y' \sin i + z' \cos i . \end{aligned} \tag{11}$$

Since satellite orbital data as transmitted are not directly positions in the x'y'z' coordinate system, but as

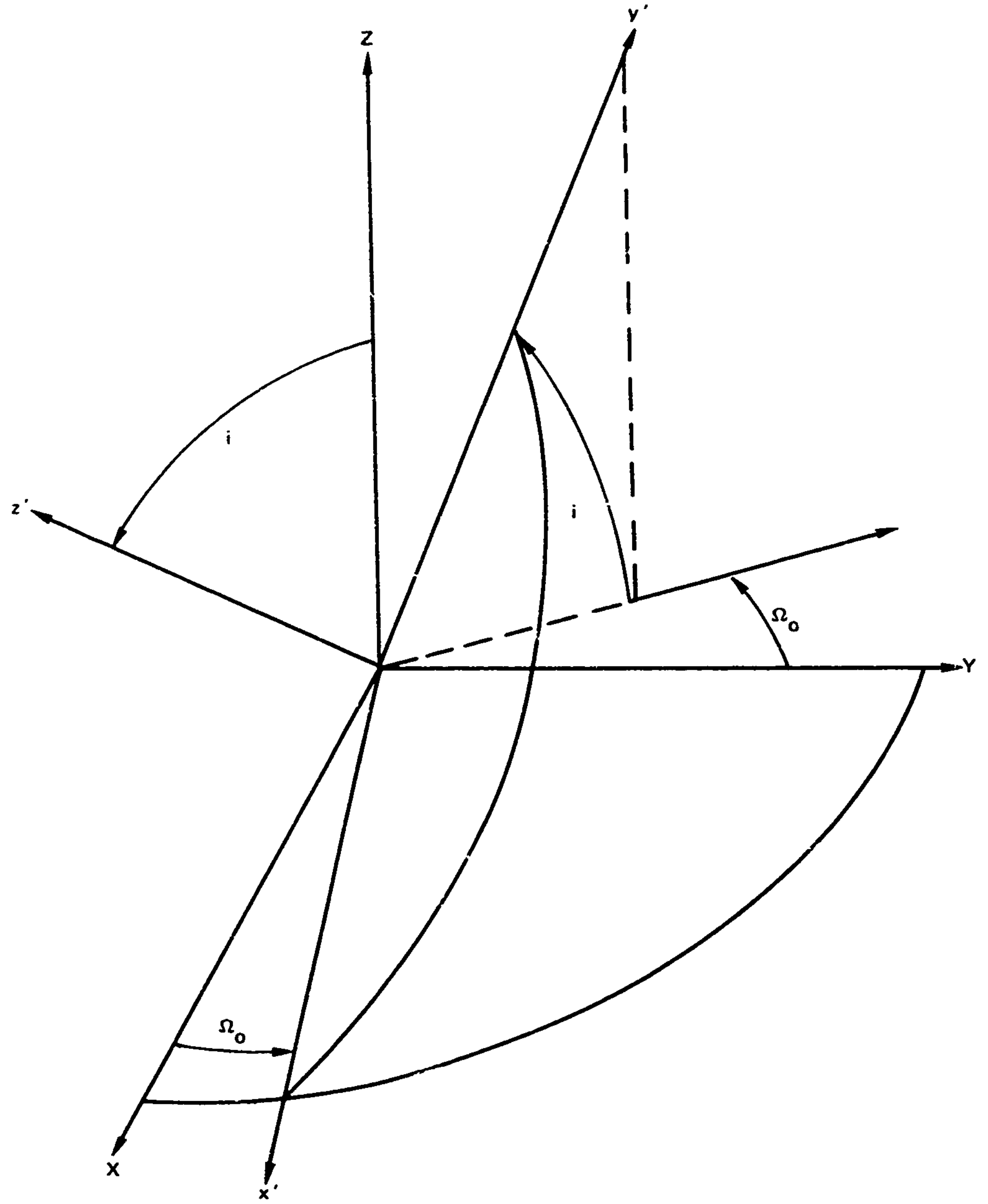


Fig. 18 x'y'z' COORDINATE SYSTEM

In Eq. (14), the mean anomaly is the same as in Eq. (13). The eccentric anomaly is given explicitly in Eq. (14). Also in Eq. (14), the factor $\sqrt{1 - \epsilon^2}$ is implicit in the expression for v_k.

In the simple classical theory, the angles Ω_o and ω_o are invariant in time. In the integrated doppler navigation computation, however, they do vary with time but are assumed to have constant time derivatives, $\dot{\Omega}$ and $\dot{\omega}$, respectively.

To summarize, in the integrated doppler navigation computation the satellite orbit is treated as a corrected ($\Delta E(t_k)$, $\Delta A(t_k)$, $\eta(t_k)$), precessing ($\dot{\omega}$, $\dot{\Omega}$) Keplerian ellipse.

The equations for computing satellite coordinates given in Step F of Section 7 follow those given here.

The term reference ellipsoid is applied here to the surface used to approximate the figure of the earth in the navigation computation. The reference ellipsoid is taken to be an ellipsoid of revolution. The axis of revolution is the z-axis or the spin axis of the earth. The center of the ellipsoid is the center of the earth.

The intersection of any plane containing the z-axis, i.e., a meridian plane, and the ellipsoid is an ellipse. The intersection of a plane parallel to the equatorial xy plane and the ellipsoid is a circle.

The rectangular coordinates (x, y, z) of any point on the surface of the ellipsoid satisfy the function F (x, y, z) = 0 in

$$F(x, y, z) = \frac{x^2 + y^2}{R_o^2} + \frac{z^2}{[R_o(1 - f)]^2} - 1 = 0 . \qquad (15)$$

In Eq. (15), R_o is the (major) equatorial semiaxis of the ellipsoid, and $R_o(1 - f)$ is the (minor) polar semiaxis.

The partial derivatives of F(x, y, z) with respect to x, y, and z are denoted by F_x, F_y, and F_z, respectively, and by Eq. (15), are

$$
\begin{aligned}
F_x &= \frac{2x}{R_o^2} \\
F_y &= \frac{2y}{R_o^2} \qquad\qquad (16) \\
F_z &= \frac{2z}{[R_o(1-f)]^2} \; .
\end{aligned}
$$

Any (outward directed) normal to the ellipsoid is inclined at an angle to the equatorial xy plane, which is denoted by φ. The angle between the x-axis and the projection of the normal on the xy plane is denoted by λ. Therefore, the direction cosines of the normal with respect to x-, y-, and z-axes are, respectively, ($\cos\varphi$, $\cos\lambda$), ($\cos\varphi$, $\sin\lambda$), and $\sin\varphi$. These direction cosines are given by

$$
\begin{aligned}
\cos\varphi \cos\lambda &= F_x/(F_x^2 + F_y^2 + F_z^2)^{1/2} \\
\cos\varphi \sin\lambda &= F_y/(F_x^2 + F_y^2 + F_z^2)^{1/2} \qquad\qquad (17) \\
\sin\varphi &= F_z/(F_x^2 + F_y^2 + F_z^2)^{1/2} \; .
\end{aligned}
$$

From Eqs. (16) and (17), we find

parameters defining its elliptical orbit, it is necessary to define an additional coordinate system, uvw, in which the w and z' axes are coincident and in which the angle ω_o, between the x' and u axes is called the argument of perigee. Figure 19 shows the relation between the x'y' and uv planes. The transformation from uvw to x'y'z' coordinates is given by

$$\begin{aligned} x' &= u \cos \omega_o - v \sin \omega_o \\ y' &= u \sin \omega_o + v \cos \omega_o \\ z' &= w \, . \end{aligned} \tag{12}$$

Now consider the pictorial representation of the satellite orbit as shown in Fig. 20. The point 0' is the center of the ellipse PSA and of the circumscribed circle PCA. The origin of the uvw coordinate system is taken as 0. The uv coordinates are shown. The w coordinate is the axis pointing off the page on Fig. 20.

Now define the time at which the satellite is at its perigee P as t_p and call it time of perigee. The position of the satellite at an arbitrary time t after t_p is represented by the point S on the ellipse PSA. The orbital ellipse has a semimajor axis denoted by A_o and an eccentricity denoted by ϵ. The angle E is called the eccentric anomaly and is the angle through which the satellite has moved on the ellipse since t_p. Further let T denote the orbital period of the satellite; then n, the mean motion, is given by $2\pi/T$.

SATELLITE AND NAVIGATOR POSITIONS

A problem in classical orbits is this: given A_o, ϵ, t_p, and t, find u(t), v(t), and w(t), the coordinates of S at time t. The computation that provides the solution of this problem is defined by Eq. (13):

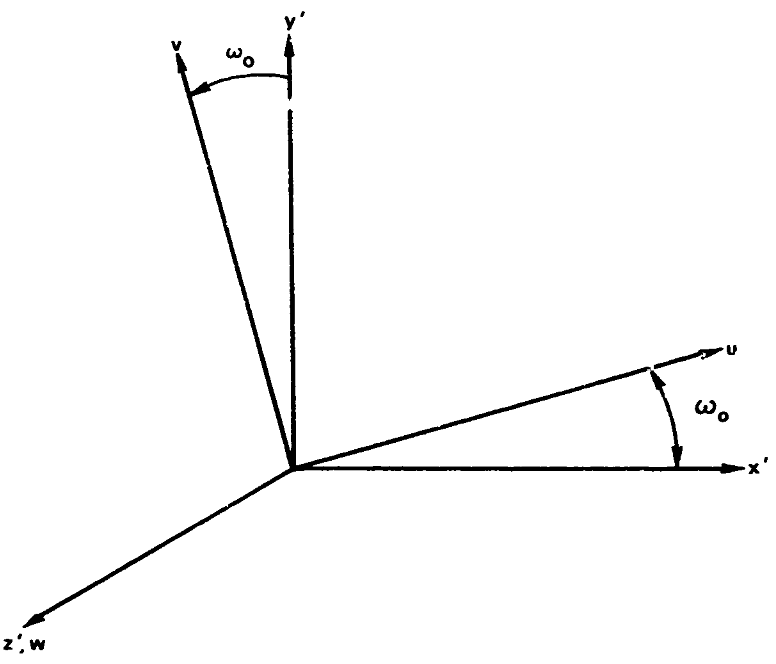


Fig. 19 RELATION BETWEEN x'y' AND uv PLANES

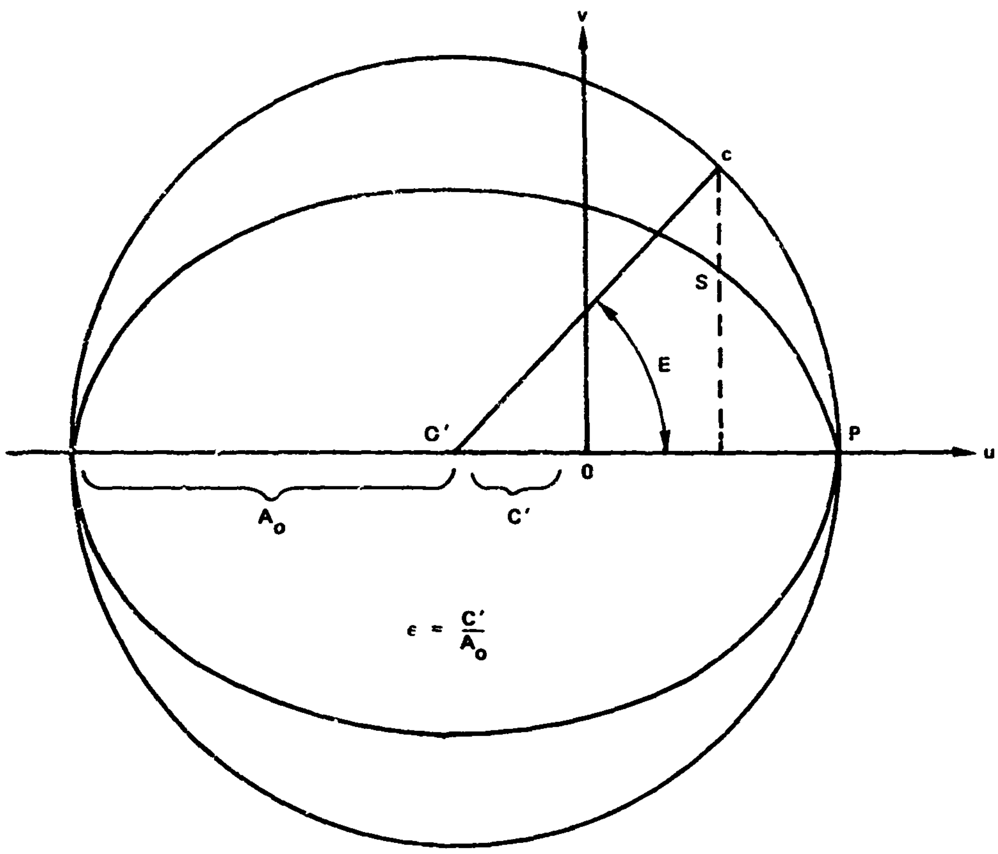


Fig. 20 SATELLITE ORBIT

$$
\begin{aligned}
M(t) &= n(t-t_p) \\
E(t) &= M(t) + \epsilon \sin E(t) \\
A &= A_c \\
u(t) &= A(\cos E(t) - \epsilon \\
v(t) &= A\sqrt{1-\epsilon^2} \sin E(t) \\
&w(t) \text{ is undefined.}
\end{aligned}
\tag{13}
$$

The quantities M(t) and E(t) in Eq. (13) are called the mean and eccentric anomalies, respectively. The equation defining E(t) (Kepler's Equation) is transcendental, and its solution can be obtained by various means.

For the integrated doppler navigation computation, this part of the computation of the satellite coordinates is carried out in a different manner.

The integrated doppler navigation problem can be stated as follows: given A_o, ϵ, n, t_p, $\Delta E(t_k)$, $\Delta A(t_k)$, and $\eta(t_k)$, find $u(t_k)$, $v(t_k)$, and $w(t_k)$. The equations which define the computation are given by

$$
\begin{aligned}
M_k &= n\,(t_k - t_p) \\
E_k &= M_k + \epsilon \sin M_k + \Delta E(t_k) \\
A_k &= A_o + \Delta A(t_k) \\
u_k &= A_k\,(\cos\,(E_k) - \epsilon) \\
v_k &= A_k \sin\,(E_k) \\
w_k &= \eta(t_k).
\end{aligned}
\tag{14}
$$

$$
\begin{aligned}
x/R_o &= F_x R_o/2 = (R_o/2)(F_x^2 + F_y^2 + F_z^2)^{1/2} \cos\varphi \cos\lambda \\
y/R_o &= F_y R_o/2 = (R_o/2)(F_x^2 + F_y^2 + F_z^2)^{1/2} \cos\varphi \sin\lambda \qquad (18) \\
z/R_o(1-f) &= F_z R_o(1-f)/2 = [R_o(1-f)/2]\left[F_x^2 + F_y^2 + F_z^2\right]^{1/2} \sin\varphi .
\end{aligned}
$$

Now, by Eq. (15)

$$(x/R_o)^2 + (y/R_o)^2 + [z/R_o(1-f)]^2 = 1. \qquad (19)$$

Expanding Eq. (19) in terms of the right-hand side of Eq. (18), we determine

$$(F_x^2 + F_y^2 + F_z^2) = \frac{4}{R_o^2 \cos^2\varphi + [R_o(1-f)]^2 \sin^2\varphi} \qquad (20)$$

Substituting from Eq. (20) for $(F_x^2 + F_y^2 + F_z^2)^{1/2}$ in Eq. (18), we obtain for the rectangular coordinates of any point on the surface of the ellipsoid:

$$
\begin{aligned}
x(\varphi, \lambda) &= \frac{R_o \cos\varphi \cos\lambda}{(\cos^2\varphi + (1-f)^2 \sin^2\varphi)^{1/2}} \\
y(\varphi, \lambda) &= \frac{R_o \cos\varphi \sin\lambda}{(\cos^2\varphi + (1-f)^2 \sin^2\varphi)^{1/2}} \qquad (21) \\
z(\varphi) &= \frac{R_o (1-f)^2 \sin\varphi}{(\cos^2\varphi + (1-f)^2 \sin^2\varphi)^{1/2}}
\end{aligned}
$$

The angular coordinates φ and λ are called the geodetic latitude and longitude, respectively, of a point

on the geodetic surface. Points not on the geodetic surface can be given a geodetic representation by means of a third coordinate, the geodetic altitude, which is denoted by h. The geoidal height above the reference ellipsoid is denoted by H, and $h' = (h + H)$.

A value for H in meters may be determined through use of Fig. 21, a geoidal height contour map. To use this map the navigator locates the approximate position on it and interpolates between contour lines to obtain the value for geoidal height in meters.

Let (x, y, z) represent the coordinates of any point in space. The h' is defined to be the distance from the point to the geodetic surface. The coordinate h is positive if the point (x, y, z) is above the surface. To be specific, $h' \gtrless 0$ according to

$$\frac{x^2 + y^2}{R_o^2} + \frac{z^2}{R_o^2 (1-f)^2} \gtrless 1 .$$

Now let

$$D(\varphi) = (R_o^2 \cos^2 \varphi + [R_o (1-f)]^2 \sin^2 \varphi)^{1/2} . \tag{22}$$

Then the earth-fixed rectangular coordinates (x, y, z) of a point having the geodetic coordinates (φ, λ, h') are given by

$$\begin{aligned} x(\varphi, \lambda, h') &= \left[\frac{R_o^2}{D(\varphi)} + h'\right] \cos\varphi \cos\lambda \\ y(\varphi, \lambda, h') &= \left[\frac{R_o^2}{D(\varphi)} + h'\right] \cos\varphi \sin\lambda \\ z(\varphi, h') &= \left[\frac{R_o^2(1-f)^2}{D(\varphi)} + h'\right] \sin\varphi . \end{aligned} \tag{23}$$

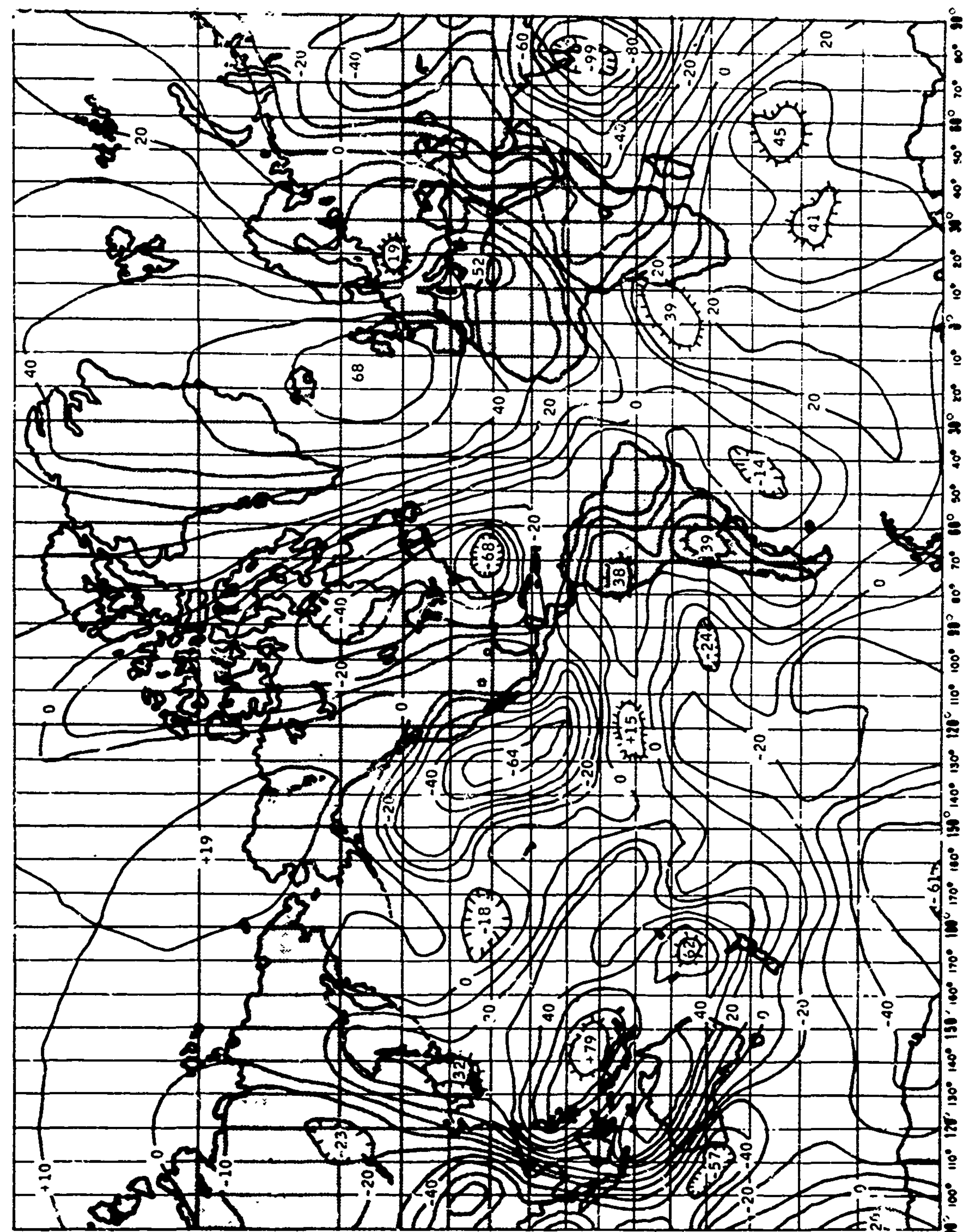


Fig. 21 GEOIDAL HEIGHT (H) CONTOUR MAP (METERS)

In the integrated doppler navigation computation, use is made of the partial derivative of x, y, and z with respect to φ and λ. A partial derivative with respect to φ is denoted by superscript $(^2)$ and with respect to λ by superscript $(^3)$. From Eqs. (22) and (23), it is seen that

$$
\begin{aligned}
x^{(2)}(\varphi, \lambda, h') &= -\left(\left(R_o^{\,2}\,[R_o(1-f)]^2/D^3(\varphi)\right) + h'\right)\sin\varphi\cos\lambda \\
y^{(2)}(\varphi, \lambda, h') &= -\left(\left(R_o^{\,2}\,[R_o(1-f)]^2/D^3(\varphi)\right) + h'\right)\sin\varphi\sin\lambda \\
z^{(2)}(\varphi, h') &= \left(R_o^{\,2}\,[R_o(1-f)]^2/D^3(\varphi)\right) + h'\right)\cos\varphi \\
x^{(3)}(\varphi, \lambda, h') &= -y(\varphi, \lambda, h') \\
y^{(3)}(\varphi, \lambda, h') &= x(\varphi, \lambda, h')\,.
\end{aligned}
\tag{24}
$$

5. DATA TYPES AND FORMATS

TYPES OF DATA

Four types of data are processed for entry into the navigation solution equations. These data types are

1. Doppler and refraction data,
2. Satellite orbital data,
3. Navigator's estimates of time (GMT) of first fiducial mark, position, antenna height, heading, ship's velocity, day number of pass, and alert instructions, and
4. Program constants.

Doppler and Refraction Data

Section 3 describes the doppler and refraction data obtained from the ITT and Magnavox equipment, respectively.

Satellite Orbital Data

During every 2 minutes of a satellite pass, data describing the orbit are transmitted from the satellite in 156 BCDX3 words of 39 bits each plus an additional 19 bits. The data are in two groups: fixed parameters, describing a precessing Kepler ellipse that approximates the satellite orbit; and variable parameters, describing the deviations of the orbit from the precessing ellipse for each 2-minute interval. Tables 1 and 2 describe the variable and fixed parameters, respectively.

Each of the eight variable data words consists of the parameters t_k, ΔE_k, ΔA_k, and η_k combined in a single word. Of the eight variable words the fourth word (satellite word No. 26) describes the orbit deviations from the precessing ellipse for the present 2-minute interval. The

Table 1

Variable Orbit Parameters in Navigation Message

Satellite Word No [1]	Parameter Symbol	Units	No of Digits	Sign	Magnitude	Definition of Parameter
	t_k	Minutes modulo 15	2	[2]	XX. 0	Time in integer even UT minutes following an integer one-half hour of kth transmission
8, 14, 20, 26, 32, 38, 44, and 50	ΔE_k	Degrees	3	[2]	0 0XXX	Correction to eccentric anomaly for kth time point
	ΔA_k	Meters	3	[2]	XXX0. 0	Correction to mean semimajor axis for kth time point
	η_k	Meters	2	[3]	XX0. 0	Out of plane orbit component

[1] Each word of variable orbit data is a 9-digit combination of the parameters t_k, ΔE_k, ΔA_k, and η_k. The method of combination is as follows, where each of the 9 digits is represented by the letter X:

X	X	XXX	XXX	X
Code value for signs of ΔE_k and ΔA_k and first digit of t_k	Second digit of t_k	Value of ΔE_k	Value of ΔA_k	One digit of η_k

[2] The decimal code value for the signs of ΔA_k and ΔE_k and for the first digit of t_k is as follows:

Sign of ΔA_k	Sign of ΔE_k	First Digit of t_k	Decimal Code Value
+	+	0	0
-	+	0	1
+	-	0	2
-	-	0	3
+	+	1	4
-	+	1	5
+	-	1	6
-	-	1	7

[3] Quantity η consists of two digits $\eta^{(m)}$ and $\eta^{(1)}$, the digits being transmitted in successive 2-minute messages. In reconstructed form, $\eta = \pm 0.\eta^{(m)}\,\eta^{(1)}$, and is partitioned as follows: $\eta^{(m)}$ is transmitted in each variable parameter word whose fiducial time (UT) in minutes is divisible by 4 (zero included); $\eta^{(1)}$ is transmitted in the next 2-minute message. In addition, $\eta^{(m)}$ is transmitted in a code that indicates both value and sign. The code is:

Decimal Equivalent of Transmitted BCDX3 Digit (D_2)	$\eta^{(m)}$	Decimal Equivalent of Transmitted BCDX3 Digit (D_2)	$\eta^{(m)}$
0	-0	5	+0
1	-4	6	+1
2	-3	7	+2
3	-2	8	+3
4	-1	9	+4

The decoding for $\eta^{(m)}$ is as follows: $\eta^{(m)} = (D_2 - 5)$ when $1 \leq D_2 \leq 9$. When $D_2 = 0$, $\eta^{(m)} = -0$. When $D_2 = 5$, $\eta^{(m)} = +0$. The quantity $\eta^{(1)}$ is not coded. It should be noted that t_k is modulo 15 (i.e., 30 minutes) whereas the time associated with η_k is modulo 60 minutes. Values of η_k for fiducial times not divisible by 4 are obtained by interpolation.

Table 2

Fixed Orbit Parameters in Navigation Message

Satellite Word No.	Parameter Symbol	Units	No. of Digits	Sign and Magnitude[1]	Definition of Parameter
56	t_p	Minutes UT modulo 1440	9	TXXX. XXXXX	Time of first perigee in the time span of ephemeral memory on the day when that perigee occurs
62	n	Degrees/ minute minus three[2]	9	S. XXXXXXXX	Mean motion of satellite
68	ω_o	Degrees	9	SXXX. XXXXX[3]	Argument of perigee at t_p
74	$\dot{\omega}$	Degrees/ minute	9	S. XXXXXXXX	Precession rate of perigee
80	ϵ	Dimension-less	9	SX. XXXXXXX	Eccentricity
86	A_o	Meters	9	SXXXXXXXX. 0[3]	Mean semimajor axis
92	Ω_o	Degrees	9	SXXX. XXXXX[3]	Right ascension of ascending node at t_p
98	$\dot{\Omega}$	Degrees/ minute	9	S. XXXXXXXX	Precession rate of node
104	Ci	Dimension-less	9	SX. XXXXXXX	Cosine of inclination
110	Λ_G	Degrees modulo 360	9	SXXX. XXXXX[3]	Inertial longitude of Greenwich relative to Aries at t_p
116	ΔM	----	9	----	Change in mean anomaly for 1-hour time interval (unused).
122	δM	Minutes UT	9	----	Change in mean anomaly for 2-minute time interval (unused).
128	Si	Dimension-less	9	SX. XXXXXXX	Sine of inclination
134	$\Delta\gamma_s$	----	9	----	Satellite frequency offset (unused)
140, 146 and 152	--	----	9	---	Zeros at time of injection[4]

[1]The first digit of each word is coded as follows:

T is transmitted as either 0 or 4; 0 is interpreted as 0, 4 is interpreted as 1.
S is transmitted as either 8 or 9; 8 is interpreted as +, 9 is interpreted as -.

[2]The value of n as received reflects only the fractional portion of n. The value should be 3. XXXXXXXX and can be obtained by adding 3 to the received value.

[3]Always a positive value.

[4]Words 122, 140, 146, and 152 are not necessary to the fix computations but may prove helpful in the detection of satellite memory injections.

third word (satellite word No. 20) is for the previous 2-minute interval. The fifth word (satellite word No. 32) is for the following 2-minute interval. The variable words are updated every 2 minutes such that variable word 2 becomes variable word 1, 3 becomes 2, 4 becomes 3, etc., and a new variable word is introduced from satellite memory to replace variable word 8. Variable word 1 is lost. In this way the observer receives not only the variable words for the present 2-minute interval, but also data for the past three 2-minute intervals and the four future 2-minute intervals.

During data processing (described in Section 6) the satellite orbital data are validated by a majority vote procedure that accepts data as error-free when agreement is found in two out of three instances. The data are also processed into tables for convenient use in the navigation solution.

Navigator's Estimates

Table 3 lists the data that the navigator is required to enter into the computer for the navigation solution.

Program Constants

The values of the program constants used in the navigation solution computation are listed in Table 4.

DATA FORMATS

All the satellite data are in the form of BCDX3 binary bits which can be converted to decimal characters. Doppler data require seven characters, or 28 bits. ITT refraction data require four characters; Magnavox refraction data require seven characters. From Tables 1 and 2 it is seen that an orbital data word requires nine characters.

The satellite transmits orbital data in 39-bit words. Bits 37-39 of each word, however, are reserved for parity,

Table 3

Navigator's Estimates

Parameter	Symbol	Units	Magnitude
Time of first fiducial mark	T_c	Hours and minutes GMT	XX h, XX min
Position:			
Latitude	φ_e	Degrees and minutes	±XX°, XX. XXX′ + = north - = south
Longitude	λ_e	Degrees and minutes	±XXX°, XX. XXX′ + = east - = west
Antenna height	h	Meters	±XX. X[1]
Heading (course)[2]	d	Degrees clockwise from true north	XXX. X°
Rate (speed)[2]	v	knots	XX. X
Day number of pass	IDAY	Days	XXX.
Alerts:			
Day number of last Day for which alerts are to be calculated	MDAY[3]	Days	XXX.

[1] Dependent upon installation; see Fig. 21.

[2] If equipment such as SINS is available, the navigator may use latitude and longitude data at each fiducial mark instead of heading and rate.

[3] If MDAY = IDAY, no alerts will be calculated.

Table 4

Program Constants

Parameter	Symbol	Units	Magnitude
		System Constants	
Initial value of offset frequency	$\bar{f}_o$	cycles/second	32,000
Vacuum wavelength at reference frequency	L_o	m/cycle	7.4948125×10^{-1}
		Earth Constants	
Rotation rate of earth with respect to x, y, z coordinate system	ω_e	rad/min	4.3752695×10^{-3}
Equatorial radius of reference ellipsoid	R_o	m	6 378 144
Flattening of reference ellipsoid	f	dimensionless	$\frac{1}{298.23}$

telemetry, and clock data of concern in system management. These three bits are discarded by the ITT and Magnavox equipment. For simplicity, therefore, a satellite orbital data word is defined here to have a 36-bit length, and for convenience in computer processing every 36-bit satellite orbital data word is divided in the ITT and Magnavox equipment into three 15-bit computer words. Similarly, doppler and refraction data are formatted in the equipment into three 15-bit computer words, with binary zeros being used to fill in blanks, as will be shown below.

Each 15-bit computer word consists of 12 data bits plus a 3-bit identification (ID) code generated in the receiver. The ID code serves both to identify whether the computer word represents doppler, refraction, or orbital data and also whether the computer word contains the first 12-bit segment or a later 12-bit segment of data.

ITT Interface

Figure 22 shows examples of the 15-bit computer words for orbital data, doppler data, and refraction data provided by the ITT equipment. The 15-bit computer word is transferred from the receiver on 15 data lines denoted 2^0 through 2^{14}. Data lines 2^0 through 2^2 are the ID codes, and lines 2^3 through 2^{14} are the actual data bits. The most significant ID bit is 2^2. The most significant data bits are 2^{14}, 2^{10}, and 2^6. Note that the zeros in front of the doppler and refraction data are binary zeros. The voltage levels of the signals are such that

logic 1 = 0 ±1.5 volts,

logic 0 = -14 ±3.5 volts.

Magnavox Interface

Figure 23 shows examples of the 15-bit computer words provided by the Magnavox 702 equipment. The 15-bit computer word is transferred from the receiver on 15 data lines designated bits 1 through 15. Bits 13 through 15 are the ID codes. Bits 1 through 12 are the actual data

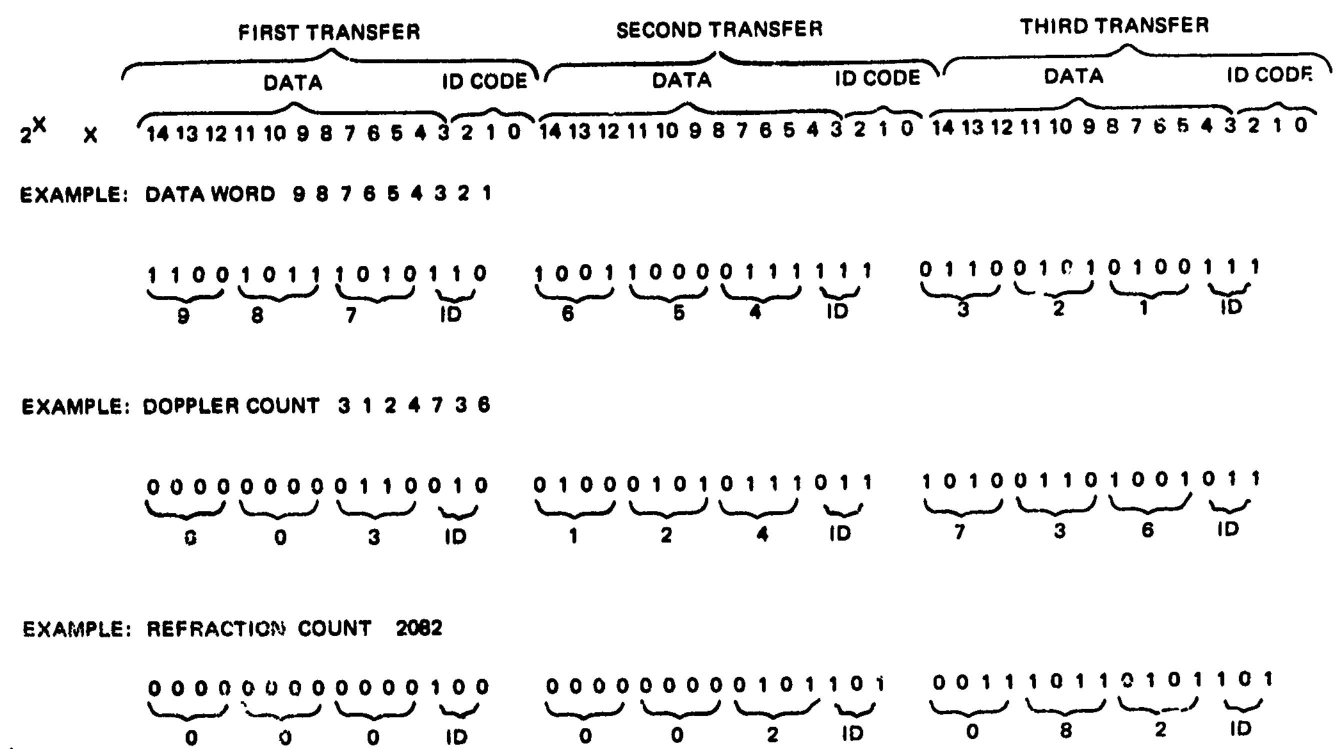
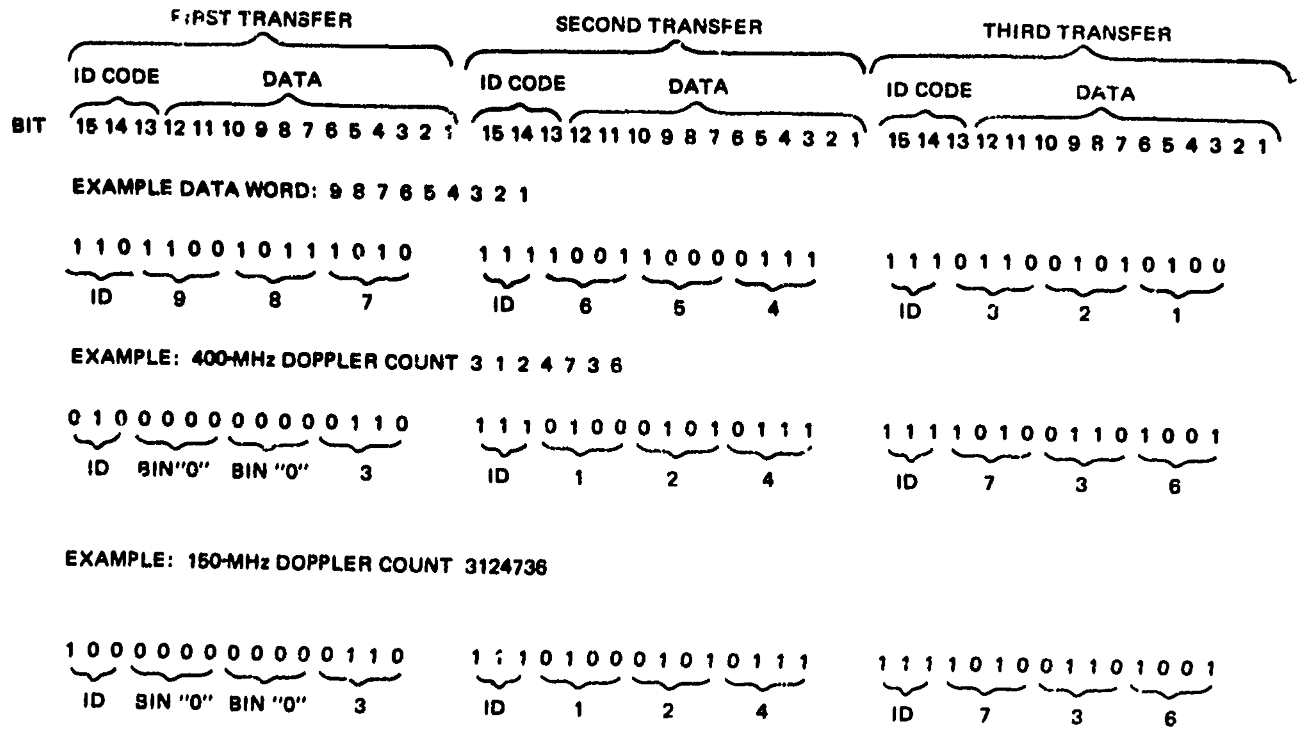


Fig. 22 DATA FORMAT FOR AN/SRN-9 EQUIPMENT



NOTE: DIFFERENCE BETWEEN 400- AND 150-MHz DOPPLER COUNTS IS INITIAL ID CODE

Fig. 23 DATA FORMAT FOR MAGNAVOX EQUIPMENT

bits. The most significant ID bit is bit 15. The most significant data bits are bits 12, 8, and 4. Note that the zeros in front of the doppler and refraction data are binary zeros. The voltage levels of the signals are such that

logic 1 = 0 ±0.25 volt,

logic 0 = +6 volts (open circuit).

Sign

A 16-bit, binary word, general purpose computer with input/output devices operating under programmed interrupt control may be used for data processing and for executing the navigation calculations. A computer of this word size accommodates the 15-bit computer word and allows the 16th bit to be used as a sign bit. All the satellite data are transmitted as positive numbers; note from Table 2, however, that positive values in some parameters represent coded values for negative numbers.

Formatting Satellite Words into Computer Words

Figure 24 defines ID codes and shows the format of 36-bit words as output from the ITT and Magnavox equipment in three computer words (each word consisting of 15 bits plus a sign bit). BCDX3 characters are shown as X's. Zeros fill in the blank spaces to make up the required 36 bits per satellite word.

Figure 25 is a timing diagram for the receiver/computer interface. In this diagram the term "word" means the 36-bit satellite orbital data word. The figure shows that in a 2-minute message transmitted from the satellite three computer words of doppler data are transferred from the receiver to the computer during the occurrence of satellite word 3, three computer words of refraction data are transferred during satellite word 5, and 75 computer words of satellite orbital parameter data are transferred during satellite words 8-152, with three computer words being transferred during each sixth satellite

TRANSFER NO.	ITT OUTPUT (SIGN ... ID)	SATELLITE DATA TYPE	MAGNAVOX OUTPUT (SIGN ID ...)
1	0 0000 0000 X 010	DOPPLER DATA	0 010 0000 0000 X
2	0 X X X 011		0 111 X X X
3	0 X X X 011		0 111 X X X
1	0 0000 0000 0000 100	REFRACTION DATA	0 100 0000 0000 X
2	0 0000 0000 X 101		0 111 X X X
3	0 X X X 101		0 111 X X X
1	0 X X X 110	ORBITAL PARAMETER DATA	0 110 X X X
2	0 X X X 111		0 111 X X X
3	0 X X X 111		0 111 X X X

X = BCDX3 CHARACTER

Fig. 24 FORMAT OF DOPPLER, REFRACTION, AND ORBITAL DATA DIVIDED INTO COMPUTER WORDS IN THE ITT AND MAGNAVOX RECEIVERS

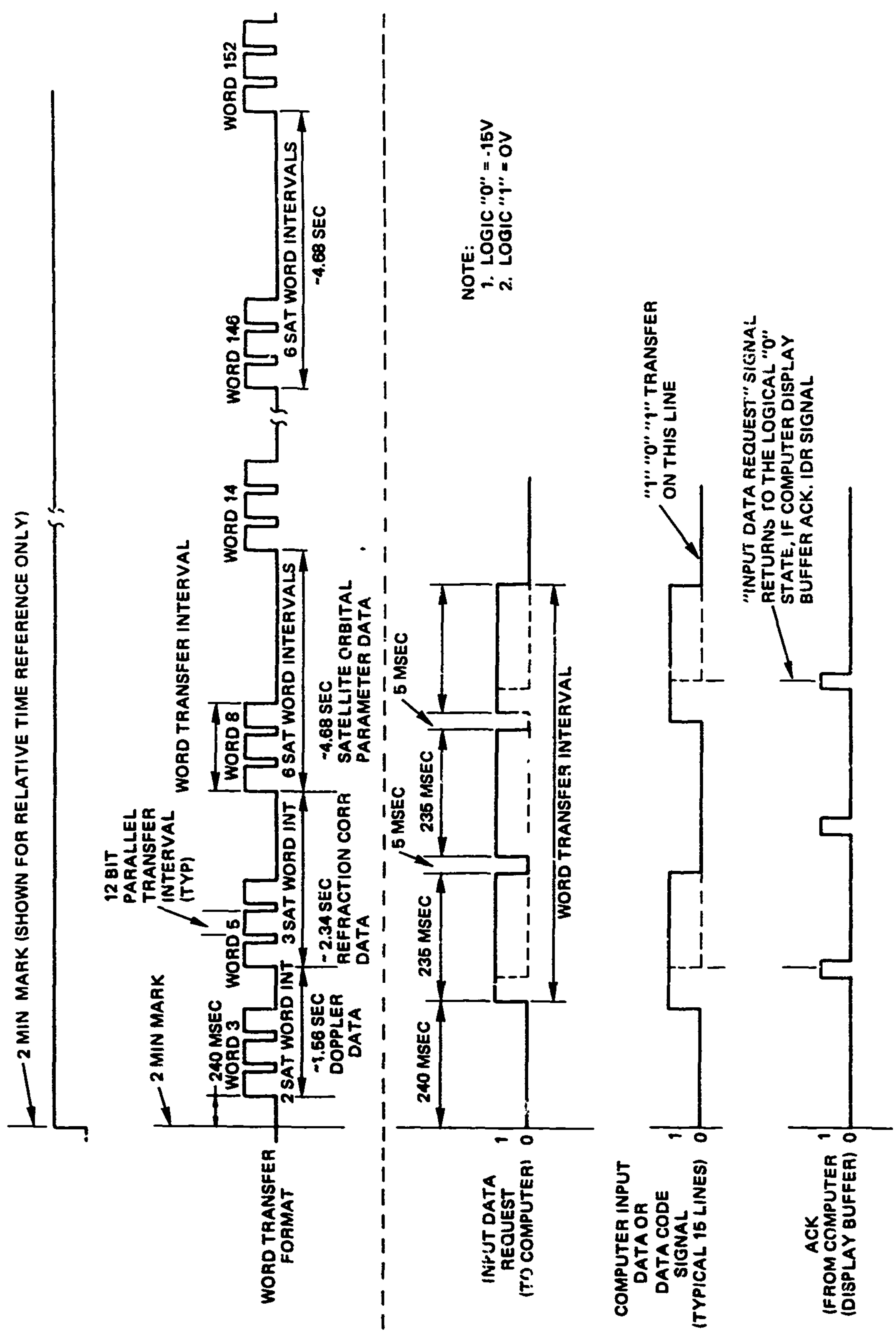


Fig. 25 RECEIVER/COMPUTER INTERFACE TIMING DIAGRAM

word. From Table 2 it may be observed that the data in satellite words 116, 122, 134, 140, 146, and 152 are not required in the navigation routine. Satellite words 122, 140, 146, and 152 contain data that may be used in determining whether the satellite message was updated during a particular 2-minute interval by the ground injection station. This feature will be described in greater detail in Section 6.

6. DATA PROCESSING

The objectives of the real-time processing done on the satellite 2-minute messages are to obtain the fixed orbital parameters, to obtain the variable orbital parameters and the doppler and refraction data and arrange them in time ordered tables with due regard for any missing data, and to check the validity and accuracy of the data in preparation for use in the calculation of the navigation fix. During this process a check is also made to determine if a new message has been injected into the satellite and appropriate action taken if it has. The data supplied by the navigator are also obtained. The processing steps to accomplish these objectives are as follows:

During the first 2-minute message the variable and fixed orbital parameters are obtained.

During the second 2-minute message the doppler data for the first 2-minute interval are obtained and validated, a check is made that the fixed and variable data were obtained during the first 2-minute message, the refraction correction data for the first 2-minute interval are obtained, and the variable and fixed orbital parameters in the second 2-minute message are obtained.

During the third 2-minute message the doppler data for the second 2-minute interval are obtained and validated, a check is made that a new message has not been injected into the satellite memory, the differences between the orbital parameters obtained in the first and second 2-minute messages are calculated, with due regard for the precession of the variable data, the refraction correction data for the second 2-minute interval are obtained and validated, and the variable and fixed orbital parameters in the third 2-minute message are obtained.

During the fourth 2-minute message the doppler and refraction data are collected and validated, the new-message check is done, and for each orbital parameter a determination is made if agreement exists in two of the three messages by a majority vote process. Finally, for any parameter for which a majority vote was not obtained, a new value is obtained from the fourth message.

These procedures are repeated during successive 2-minute messages until the satellite pass is over or until doppler and refraction data have been obtained for nine 2-minute intervals. If loss of lock occurs for a time during the pass, pointer registers keep place in the data tables and appropriate missed data entries are made. If the injection check finds that the satellite is transmitting a new message and majority voted data have not yet been obtained, message collection begins again.

At the end of the pass the data are formatted from BCDX3 to floating point and the navigator enters values for his estimates of sync time, position, antenna height, heading, rate, day number of pass, and the interval for which he desires alerts.

The following sections and accompanying flow charts describe the detailed procedures that occur during real-time data processing of each 2-minute satellite message. For convenience in later reference, the flow charts for both the data processing program described in this Section and the FORTRAN navigation program described in Section 8 are grouped together in Appendix A. The nomenclature used in the flow charts is also used in this description and will be defined at its first mention. The final part of this Section describes modifications to the real-time procedures to allow their use in postpass navigation.

INITIALIZATION

During initialization (Fig. A-1) the program constants are read into memory storage; tables and interrupt interface addresses are set to their assigned locations; and the flags, counters, and pointers used for place keeping and for denoting the status of program execution in the particular computer being used are set to their initial values and locations. Figure 26 shows, for example, the arrangement and initialized values in eight tables that are used in one representative computer program for storing the doppler, refraction, and orbital data. This arrangement requires 321 storage locations for the eight tables. The table locations (shown in octal notation) are specific to this particular computer program and are included here only for reference in discussing the data processing procedures.

The data stored in the tables are as follows: Table FPCR is used to store the fixed parameters in each 2-minute satellite message; Table FPVD is used to store the fixed parameters that either will be subjected to the majority vote test or have passed this test; Table FPER is used to keep track of those parameters that have passed the majority vote test and also the errors in those parameters which have not passed the test. Tables VPCR, VPVD, and VPER perform these same functions for the variable parameters. Tables DOPS and REFS store the doppler and refraction data, respectively.

During initialization, Tables FPCR, FPVD, VPCR, and VPVD are set to values of BCD zero, Tables FPER and VPER are set to values of binary -2, and Tables DOPS and REFS are set to values of BCDX3 zero. The -2 values in error tables FPER and VPER are used in the majority vote process, as explained in later sections. The BCDX3 zero values in the doppler and refraction tables are the values

FIXED PARAMETER CURRENT WORD (FPCR)	FIXED PARAMETER MAJORITY VOTED WORD (FPVD)	FIXED PARAMETER ERROR WORD (FPER)	VARIABLE PARAMETER CURRENT WORD (VPCR)	VARIABLE PARAMETER MAJORITY VOTED WORD (VPVD)	VARIABLE PARAMETER ERROR WORD (VPER)	DOPPLER WORD (DOPS)	REFRACTION WORD (REFS)
16223 ◄ FPR	16000 ◄ FPV	16416 ◄ FPE	16366 ◄ VPR	16143 ◄ VPV	16306 ◄ VPE	16063 ◄ D04	16113
16224	16001	16417	16367 BCD	16144 BCDX3	16307	16064	16114
16225	16002	16420	16370 −2	16145 Zero	16310	16065	16115
16226	16003	16421	16371	16146	16311	16066	16116
16227	16004	16422	16372	16147	16312	16067	16117
16230	16005	16423	16373	16150	16313	16070	16120
16231	16006	16424	16374	16151	16314	16071	16121
16232	16007	16425	16375	16152	16315	16072	16122
16233	16010	16426	16376	16153	16316	16073	16123
16234	16011	16427	16377	16154	16317	16074	16124
16235	16012	16430	16400	16155	16320	16075	16125
16236	16013	16431	16401 BCD	16156	16321	16076 BCDX3	16126 BCDX3
16237	16014	16432	16402 Zero	16157	16322	16077 Zero	16127 Zero
16240	16015	16433	16403	16160	16323	16100	16130
16241	16016	16434	16404	16161	16324	16101	16131
16242	16017	16435	16405	16162	16325	16102	16132
16243	16020	16436	16406	16163	16326	16103	16133
16244	16021	16437	16407	16164	16327	16104	16134
16245	16022	16440	16410	16165	16330	16105	16135
16246	16023	16441	16411	16166	16331	16106	16136
16247	16024	16442	15412	16167	16332	16107	16137
16250	16025	16443	13413	16170	16333	16110 ◄ RE-1	16140
16251	16026	16444	16414	16171 BCD	16334 BCD	16111	16141
16252 BCD	16027 BCD	16445 BCD	16415	16172 Zero	16335 −2	16112	16142
16253 Zero	16030 Zero	16446 −2		16173	16336		
16254	16031	16447		16174	16337		
16255	16032	16450		16175	16340		
16256	13033	16451		16176	16341		
16257	16034	16452		16177	16342		
16260	16035	16453		16200	16343		
16261	16036	16454		16201	16344		
16262	16037	16455		16202	16345		
16263	16040	16456		16203	16346		
16264	16041	16457		16204	16347		
16265	16042	16460		16205	16350		
16266	16043	16461		16206	16351		
16267	16044	16462		16207	16352		
16270	16045	16463		16210	16353		
16271	16046	16464		16211	16354		
16272	16047	16465		16212	16355		
16273	16050	16466		16213	16356		
16274	16051	16467		16214	16357		
16275	16052	16470		16215	16360		
16276	16053	16471		16216	16361		
16277	16054	16472		16217	16362		
16300	16055	16473		16220	16363		
16301	16056	16474		16221	16364		
16302	16057	16475		16222	16365		
16303	16060	16476					
16304	16061	16477					
16305	16062	16500					

Fig. 26 STATUS OF DATA TABLES AT INITIALIZATION

to which entries in these tables should be set if they represent missing entries. The other tables are set to BCD zero values to eliminate the possibility of data accumulated during previous passes from entering into the calculations for the present pass.

Figure 26 also shows the beginning locations of the eight pointer registers used to keep place in the eight data tables. In seven of the tables the pointer registers are set to the beginning addresses of the tables. For Table REFS, however, pointer register RE-1 is set to a location three entries before the beginning of Table REFS. This arrangement provides for updating the pointer registers after receipt of the doppler data, as will be described in a later section.

TEST FOR INTERRUPT

The computer on which this program is designed for execution is one that operates under interrupt control. An interrupt is an action occurring independently of the program that causes a change in the sequence of program execution. The interrupts accommodated in this program are the transfers of data from the receiver or the input-output device (assumed here to be a teletypewriter) and the transfer of data from the computer to the teletype. The occurrence of an interrupt is a computer hardware function that forces a transfer to a dedicated location in the computer memory. In the particular computer for which this program was written the dedicated location is location 63. The interrupt sequence is as follows:

After initialization, the program dwells in subroutine INP3, the test for first interrupt. Subroutine INP3 (Fig. A-1) checks, in turn, whether data have been transferred to the computer from the receiver or whether SW 2 has been set, indicating that the renavigation (ESM) option is to be executed. This latter situation will be covered at the end of the real-time procedures. In a real-time pass subroutine INP3 will be interrupted when data are entered into the computer, and program control will be transferred through dedicated location 63 to the address of subroutine INTR, the interrupt processor.

INTERRUPT PROCESSOR

Subroutine INTR (Fig. A-16) checks, in turn, whether the interrupt represents the receiver or the teletype. In a real-time pass the first interrupt will be from the receiver, signaling the beginning of the processing of the first 2-minute message. Program control will transfer to subroutine RCVD, the receiver interrupt.

ID CODE SEQUENCE

Before describing the processing of the first receiver interrupt it should be noted that if no loss of lock occurs, a total of 81 receiver interrupts in the format shown in Figs. 22 and 23 are generated during each 2-minute interval of a satellite pass. It is convenient to consider the transfer of data from the receiver in terms of the sequence of ID codes that will occur during a 2-minute message. Figure 27 shows this sequence for the ITT receiver data. The mnemonic shown under each ID code will be used in the following description of the processing of the real-time receiver data. It should be noted in Fig. 27 that the first and second occurrences of DP2, RF2, and

010 011 011 100 101 101 110 111 111 110 111 111 110 111 111 ---------- 110 111 111

DP1 DP2 DP2 RF1 RF2 RF2 MG1 MG2 MG2 MG1 MG2 MG2 MG1 MG2 MG2 MG1 MG2 MG2

doppler data

refraction data

satellite orbital parameter data (75 computer words)

Fig. 27 ID CODE SEQUENCE FOR ITT RECEIVER DATA DURING A 2-MINUTE MESSAGE

MG2 are not uniquely coded, thus necessitating the use of an interrupt count switch in the computing program to monitor sequence. In addition the transition from the ephemeral to the fixed portion of the orbital parameters is not uniquely coded and a counter is needed to monitor this transition.

RECEIVER INTERRUPT

Returning to the processing of the first receiver interrupt, subroutine RCVD (Fig. A-17) accepts the 15-bit computer word being transferred from the receiver, storing the 3-bit ID code and the 12-bits of satellite data in buffer storage registers and setting receiver flag RCFG. Three buffer registers are used for storing the satellite data, one each for the three computer word transfers that make up one satellite word. Index register XREC is used to distinguish among buffer registers. After RCFG is set, return is made through subroutine INTR to the point at which subroutine INP3 was interrupted, unless a teletype interrupt has occurred, in which case this interrupt will also be processed. Subroutine INP3 will determine that the first interrupt has occurred (by noting that receiver flag RCFG has been set), and will transfer complete program control to subroutine IDLE.

SUBROUTINE IDLE

Subroutine IDLE (Fig. A-2) is the subroutine to which the program returns after processing each of the 81 interrupts during every 2-minute message. The subroutine checks, in turn, whether a receiver interrupt has occurred, whether 2 minutes have elapsed, and whether 16 minutes of doppler data (eight doppler counts) have been collected. It also controls entry to subroutine INCR which increments time once per minute by updating program clock register CLOC. During its first execution, however, subroutine IDLE will note immediately that the first receiver interrupt has occurred and transfer program control to subroutine IDL2.

SUBROUTINE IDL2

Subroutine IDL2 (Fig. A-2) resets receiver flag RCFG in preparation for receipt of the next receiver interrupt and then tests the ID code that was stored in the buffer register during subroutine RCVD. Transfer will then be made to subroutine DP1, DP2, RF1, RF2, MG1, or MG2, depending on the value of the ID code. In normal real-time data processing the first code to be transferred after sync recognition in the receiver will be the code for subroutine DP1. Transfer to subroutine DP1 therefore marks the beginning of the processing of the first 2-minute message.

FIRST TWO-MINUTE MESSAGE

Doppler and Refraction Count Words

Subroutine DP1 (Fig. A-3) checks whether 16 minutes of doppler data have been obtained, sets the teletypewriter in preparation for data printout, resets internal program clock register CLOC to zero to mark the beginning of the 2-minute interval, and sets sync time register SYNC to a value of 2 minutes to mark the expected time of the next 2-minute interval. Doppler and refraction data are the first receiver outputs in a 2-minute message and apply to the preceding 2-minute interval. Consequently, in the first 2-minute interval after sync recognition these data are meaningless. The computer program takes cognizance of this fact by testing message sync flag FDOP. This flag will not be set until first execution of subroutine MG1. Until then the program discards the doppler and refraction data, returning to subroutine IDLE after each check for message sync in subroutines DP1, DP2, RF1, and RF2 (Figs. A-3 and A-4).

Orbital Parameter Word No. 1

First 15-Bit Transfer. The check on the ID code in subroutine IDLE of the first 15-bit transfer for orbital parameter word No. 1 directs execution of subroutine MG1.

Subroutine MG1 (Fig. A-5) begins by setting message sync flag FDOP, thus allowing data storage to begin. Inasmuch as in a 2-minute satellite message the satellite orbital parameter data are transmitted as eight variable parameters followed by the fixed parameters, the data received during orbital parameter word No. 1 and stored in the first buffer register during receiver interrupt routine RCVD are variable data. These data are placed in Variable Parameter Current Word Table VPCR at the location specified in register VPR, the pointer register for this table. The pointer register is then incremented by a value of 1. The next time data for this table are obtained from the receiver; the pointer register will indicate that the data are to be stored at the next location in the table. Interrupt count switch INTC is then set, in preparation for use during the second and third 15-bit transfers, and program control returns to subroutine IDLE.

<u>Second 15-Bit Transfer</u> The check on the ID code in subroutine IDLE of the second 15-bit transfer for orbital parameter word No. 1 directs execution of subroutine MG2.

Subroutine MG2 (Fig. A-5) begins by testing message sync flag FDOP. This flag has been set in subroutine MG1, just completed; therefore, this test directs placement of the data stored in the buffer register during receiver interrupt routine RCVD in Variable Parameter Current Word Table VPCR at the location specified in register VPR, the pointer register for this table. Program control then transfers to subroutine COLL.

Subroutine COLL (Fig. A-6) increments index register XREC, used to distinguish among the buffer registers in receiver interrupt subroutine RCVD, and then resets interrupt count switch INTC. When reset, this switch indicates first execution of subroutine MG2; when set it indicates second execution. The test on the switch after setting indicates that this is not the third interrupt for orbital parameter word No. 1, directing return to subroutine IDLE.

Third 15-Bit Transfer. During this second execution of subroutine MG2 the test in subroutine COLL (Fig. A-6) determines that this interrupt is the third 15-bit transfer and therefore directs return to subroutine MG2 (Fig. A-5). The data for the complete orbital parameter word (all three interrupts) are then converted to ASCII format in subroutine PROC (Fig. A-13) and stored for printout. Transfer is then made to subroutine PRNT.

Subroutine PRNT (Fig. A-11) retrieves the address of the register containing the ASCII-formatted data and stores this address for use in subroutine TTYT. The status of the teletypewriter is checked in subroutine TEST (Fig. A-11). The teletypewriter interrupt is enabled, and when subroutine TEST confirms that the teletypewriter is not busy, subroutine INTR (Fig. A-16) transfers program control via dedicated location 63 to subroutine TTYT (Fig. A-18), which controls the data printout. At this point, therefore, orbital parameter word No. 1 is stored in Table VPCR in BCDX3 format, as transmitted from the satellite, and also printed out on the teletypewriter in ASCII format. Return is made to subroutine MG2 (Fig. A-5) where register WORD is incremented from zero to one, marking the completion of the processing of orbital parameter word No. 1. Receiver index counter register XREC is set to zero in preparation for the processing of the next word, and program control returns to subroutine IDLE.

Orbital Parameter Words Nos. 2-25

The sequence described above for orbital parameter word No. 1 is repeated for orbital parameter words Nos. 2-25 with one difference. At the completion of the eighth word, register WORD will contain the number 8. A test on register WORD will determine that eight words have been processed and that, therefore, the next word to be processed is the first of the fixed parameters. This result directs storage of words 9-25 in Fixed Parameter Current Word Table FPCR. After word 25 the processing of the first 2-minute message is complete, and the program returns to subroutine IDLE until occurrence of the receiver

interrupt marking the beginning of the second 2-minute message.

Figure 28 shows the status of the eight data tables and pointer registers at the end of the first 2-minute message. Table FPCR in Fig. 28 has been annotated with the symbols for the fixed parameters to facilitate comparison with Table 2. In Table VFCR, sync time is designated by the symbol T_0, and the table entries are shown at the 2-minute intervals (referred to T_0) that occur in the first 2-minute message. The changes that have occurred in the major counters, registers, flags, and switches during the first 2-minute message are summarized in Table 5.

SECOND TWO-MINUTE MESSAGE

Doppler Count Word

First 15-Bit Transfer. Subroutine DP1 (Fig. A-3) proceeds as described above for the first 2-minute message through the check of message sync flag FDOP. FDOP was set at the beginning of message data word No. 1 in the first 2-minute message and thus directs execution of subroutine BCXS.

Subroutine BCXS (Fig. A-7) checks whether the doppler data stored in the buffer register during subroutine RCVD are valid BCDX3 characters. A character with a BCDX3 value between 0 and 9 (including those values) is accepted as valid. A character outside the range 0-9 is invalid; the subroutine replaces invalid characters with a value of BCDX3 zero. Return is then made to subroutine DP1 (Fig. A-3) where the valid character is stored in doppler word Table DOPS at the location given in pointer register DO4. Register DO4 is incremented, and interrupt count switch INTC is set in preparation for its later use in determining the first and second occurrences of subroutine DP2. Return is then made to subroutine IDLE.

Second 15-Bit Transfer. Subroutine DP2 (Fig. A-3) proceeds as described above for the first 2-minute message

FIXED PARAMETER CURRENT WORD (FPCR)	FIXED PARAMETER MAJORITY VOTED WORD (FPVD)	FIXED PARAMETER ERROR WORD (FPER)	VARIABLE PARAMETER CURRENT WORD (VPCR)	VARIABLE PARAMETER MAJORITY VOTED WORD (VPVD)	VARIABLE PARAMETER ERROR WORD (VPER)	DOPPLER WORD (DOPS)	REFRACTION WORD (REFS)
t_p 16223	16000 ◄ FPV	16416 {VPR	T_0-6 16366	16143 ◄ VPV	16306 {VPE	16063 ◄ D04	16113
16224	16001	16417 FPE	16367	16144 BCDX3 Zero	16307 FPR	16064	16114
16225	16002	16420	16370	16145	16310	16065	16115
η 16226	16003	16421	T_0-4 16371	16146	16311	16066	16116
16227	16004	16422	16372 Contains 8 variable parameters from first two minute message in BCDX3 format	16147	16312	16067	16117
16230	16005	16423	16373	13150	16313	16070	16120
ω_0 16231	16006	16424	T_0-2 16374	16151	16314	16071	16121
16232	16007	16425	16375	16152	16315	16072	16122
16233	16010	16426	16376	16153	16316	16073	16123
$\dot{\omega}$ 16234	16011	16427	T_0 16377	16154	16317	16074	16124
16235	16012	16430	16400	16155	16320	16075 BCDX3 Zero	16125 BCDX3 Zero
16236	16013	16431	16401	16156	16321	16076	16126
ϵ 16237	16014	16432	T_0+2 16402	16157	16322	16077	16127
16240	16015	16433	16403	16160	16323	16100	16130
16241	16016	16434	16404	16161	16324	16101	16131
A_0 16242	16017	16435	T_0+4 16405	16162	16325	16102	16132
16243	16020	16436	16406	16163	16326	16103	16133
16244	16021	16437	16407	16164	16327	16104	16134
Ω_0 16245 Contains 17 fixed parameters from first two minute message in BCDX3 format	16022	16440	T_0+6 16410	16165	16330	16105	16135
16246	16023	16441	16411	16166	16331	16106	16136
16247	16024	16442	16412	16167	16332	16107	16137
$\dot{\Omega}$ 16250	16025	16443	T_0+8 16413	16170	16333	16110 ◄ RE-1	16140
16251	16026	16444	16414	16171	16334	16111	16141
16252	16027 BCD Zero	16445 BCD −2	16415	16172	16335 BCD −2	16112	16142
Ci 16253	16030	16446		16173 BCD Zero	16336		
16254	16031	16447		16174	16337		
16255	16032	16450		16175	16340		
Λ_G 16256	16033	16451		16176	16341		
16257	16034	16452		16177	16342		
16260	16035	16453		16200	16343		
16261	16036	16454		16201	16344		
16262	16037	16455		16202	16345		
16263	16040	16456		16203	16346		
16264	16041	16457		16204	16347		
16265	16042	16460		16205	16350		
16266	16043	16461		16206	16351		
Si 16267	16044	16462		16207	16352		
16270	16045	16463		16210	16353		
16271	16046	16464		16211	16354		
16272	16047	16465		16212	16355		
16273	16050	16466		16213	16356		
16274	16051	16467		16214	16357		
16275	16052	16470		16215	16360		
16276	16053	16471		16216	16361		
16277	16054	16472		16217	16362		
16300	16055	16473		16220	16363		
16301	16056	16474		16221	16364		
16302	16057	16475		16222	16365		
16303	16060	16476					
16304	16061	16477					
16305	16062	16500					

Fig. 28 STATUS OF DATA TABLES AND POINTER REGISTERS AT END OF FIRST TWO-MINUTE MESSAGE

Table 5

Summary of Changes in Major Counters, Registers, Flags, and Switches During the First 2-Minute Message

Name	Mnemonic	Action
ESM/Real-Time Switch	SW2	Set to real-time position.
Interrupt Count Switch	INTC	Set in subroutine MG1, reset in first execution of subroutine MG2, set in second execution of subroutine MG2.
Orbital Word Counter	WORD	Initialized to zero; incremented at each odd execution of subroutine MG2.
Receiver Interrupt Flag	RCFC	Set in subroutine RCVD; reset in subroutine IDL2.
Program Clock Register	CLOC	Initialized to zero; incremented once per minute in subroutine INCR.
Sync Time Register	SYNC	Initialized to zero; reset to a value of 2 minutes in subroutine DP1.
Message Sync Flag	FDOP	Initialized to zero; set in subroutine MG1.
Receiver Index Counter	XREC	Initialized to zero; incremented in each execution of subroutines MG1 and MG2; set to zero at end of subroutine MG2.

through the check of message sync flag FDOP. As stated in the previous section, FDOP was set at the beginning of message data word No. 1 in the first 2-minute message and thus directs execution of subroutine BCXS.

Subroutine BCXS (Fig. A-7) and the storage of the doppler word in doppler word Table DOPS proceed as described in the previous section. Subroutine COLL (Fig. A-6) then checks for the second or third interrupt. Since this is the second 15-bit transfer, return is made to subroutine IDLE.

Third 15-Bit Transfer. During this second execution of subroutine DP2, the test in subroutine COLL (Fig. A-6) determines that this interrupt is the third 15-bit transfer and therefore directs return to subroutine DP2 (Fig. A-3). A test is made to confirm that the value stored in Table DOPS during the previous execution of subroutine DP1 is not BCDX3 zero. If it is not, this result is construed as a valid transfer, doppler flag DPFG is incremented, and program controltransfers to subroutine VALD.

Subroutine VALD (Fig. A-8) begins by testing for an injection. At this point it is assumed that the test finds no injection has occurred; the section on Injection during Pass describes the program procedures when injection has occurred. Program control then transfers to subroutine VALI.

Subroutine VALI (Fig. A-9) examines, in turn, the status of error Tables FPER and VPER for the fixed and variable parameters, respectively. At this point in the second 2-minute message these tables contain the value -2. The subroutine increments the error tables to a value of -1, and fills Tables FPVD and VPVD with the values in Tables FPCR and VPCR, respectively. Majority vote count register MJV1 is incremented, and program control transfers to subroutine UPTB.

Subroutine UPTB (Fig. A-7) increments message count register MSCT from zero to one and resets the addresses of the pointer registers for the eight data tables

to their initialization values. A test is then made on message count register MSCT, which advances the values in the pointer registers for Tables VPVD, VPER, DOPS, and REFS three locations per message. The MSCT value of 1 directs advancement of the four pointer registers by three locations. Figure 29 shows the status of the eight data tables and pointer registers after execution of subroutine UPTB.

The doppler data are converted to ASCII format in subroutine PROC (Fig. A-13) and printed out on the teletype in subroutine PRNT (Fig. A-11) in the same manner as described for orbital parameter word No. 1 in the previous section on the Third 15-Bit Transfer. Program control returns to subroutine IDLE.

Refraction Count Word

First 15-Bit Transfer. The check on the ID code in subroutine IDLE of the first 15-bit transfer for refraction count word No. 1 directs execution of subroutine RF1.

Subroutine RF1 (Fig. A-4) finds that message sync flag FDOP has been set and therefore stores the data in refraction Table REFS at the location specified by pointer register RE-1. From Fig. 24 note that the value for this first transfer of refraction data is always equal to BCD zero. Program control then returns to subroutine IDLE.

Second and Third 15-Bit Transfers. The check on the ID code in subroutine IDLE of the second and third 15-bit transfers for refraction count word No. 1 directs execution of subroutine RF2.

Subroutine RF2 (Fig. A-4) is executed twice, and the sequence for table storage and printout just described for the doppler data is repeated for the refraction data.

Orbital Parameter Words Nos. 1-25

The sequence described above for orbital parameter words Nos. 1-25 in the first 2-minute message is

FIXED PARAMETER CURRENT WORD (FPCR)	FIXED PARAMETER MAJORITY VOTED WORD (FPVD)	FIXED PARAMETER ERROR WORD (FPER)	VARIABLE PARAMETER CURRENT WORD (VPCR)	VARIABLE PARAMETER MAJORITY VOTED WORD (VPVD)	VARIABLE PARAMETER ERROR WORD (VPER)	DOPPLER WORD (DOPS)	REFRACTION WORD (REFS)
t_p 16223 ◄ FPR	t_p 16000 ◄ FPV	16416 ◄ FPE	T_0-6 16366 ◄ VPR	T_0-6 16143	16306	16063	16113 ◄ RE-1
16224	16001	16417	16367	16144	16307	16064 N_1	16114
16225	16002	16420	16370	16145	16310	16065	16115
η 16226	η 16003	16421	T_0-4 16371	T_0-4 16146 ◄ VPV	16311 ◄ VPE	16066 ◄ D04	16116
16227	16004	16422	16372	16147	16312	16067	16117
16230	16005	16423	16373 Contains	16150 Contains	16313	16070	16120
ω_0 16231	ω_0 16006	16424	T_0-2 16374 8 variable	T_0-2 16151 8 variable	16314	16071	16121
16232	16007	16425	16375 para-	16152 para-	16315	16072	16122
16233	16010	16426	16376 meters	16153 meters	16316	16073	16123
$\dot{\omega}$ 16234	$\dot{\omega}$ 16011	16427	T_0 16377	T_0 16154	16317	16074	16124
16235	16012	16430	16400 from	16155 from	16320 BCD	16075 BCDX3	16125 BCDX3
16236	16013	16431	16401 first	16156 first	16321 −1	16076 Zero	16126 Zero
ϵ 16237	ϵ 16014	16432	T_0+2 16402 two	T_0+2 16157 two-	16322	16077	16127
16240	16015	16433	16403 minute	16160 minute	16323	16100	16130
16241	16016	16434	16404 message	16161 message	16324	16101	16131
A_0 16242	A_0 16017	16435	T_0+4 16405	T_0+4 16162	16325	16102	16132
16243	16020	16436	16406 in	16163 in	16326	16103	16133
16244	16021	16437	16407 BCDX3	16164 BCDX3	16327	16104	16134
Ω_0 16245 Contains	Ω_0 16022 Contains	16440	T_0+6 16410 format	T_0+6 16165 format	16330	16105	16135
16246 17 fixed	16023 17 fixed	16441	16411	16166	16331	16106	16136
16247 para-	16024 para-	16442	16412	16167	16332	16107	16137
$\dot{\Omega}$ 16250 meters	$\dot{\Omega}$ 16025 meters	16443	T_0+8 16413	T_0+8 16170	16333	16110	16140
16251	16026	16444	16414	16171	16334	16111	16141
16252 from	16027 from	16445	16415	16172	16335	16112	16142
C_i 16253 first	C_i 16030 first	16446 BCD		16173	16336		
16254 two	16031 two	16447 −1		16174	16337		
16255 minute	16032 minute	16450		16175	16340		
Λ_G 16256 message	Λ_G 16033 message	16451		16176	16341		
16257	16034	16452		16177	16342		
16260 in	16035 in	16453		16200	16343		
16261 BCDX3	16036 BCDX3	16454		16201	16344		
16262 format	16037 format	16455		16202	16345		
16263	16040	16456		16203	16346		
16264	16041	16457		16204	16347 BCD		
16265	16042	16460		16205 BCD	16350 −2		
16266	16043	16461		16206 Zero	16351		
S_i 16267	S_i 16044	16462		16207	16352		
16270	16045	16463		16210	16353		
16271	16046	16464		16211	16354		
16272	16047	16465		16212	16355		
16273	16050	16466		16213	16356		
16274	16051	16467		16214	16357		
16275	16052	16470		16215	16360		
16276	16053	16471		16216	16361		
16277	16054	16472		16217	16362		
16300	16055	16473		16220	16363		
16301	16056	16474		16221	16364		
16302	16057	16475		16222	16365		
16303	16060	16476					
16304	16061	16477					
16305	16062	16500					

Fig. 29 STATUS OF DATA TABLES AND POINTER REGISTERS AFTER SUBROUTINE UPTB IN SECOND TWO-MINUTE MESSAGE

repeated for these same words in the second 2-minute message. Figure 30 shows the status of the eight data tables and pointer registers at the end of the second 2-minute message. The changes that have occurred in the major counters, registers, flags, and switches during the second 2-minute message are summarized in Table 6.

THIRD AND FOURTH TWO-MINUTE MESSAGES

During the third execution of the subroutines described above for the first and second 2-minute messages, subroutine VALI (Fig. A-9) will find a BCD value of -1 stored in error Table FPER and the first 24 positions of error Table VPER.

With respect to the fixed parameters, this result directs execution of an exclusive-or comparison, line by line, of the entries in Tables FPCR and FPVD, with the result of the comparison being stored on the corresponding line in Table FPER. Inasmuch as an exclusive-or comparison yields a one bit for each two binary bits that are different, but a zero bit for each two binary bits that are alike, the resultant entries in Table FPER will be the differences between the entries in Tables FPCR and FPVD. In this particular program, which uses two's complement arithmetic, the numbers -2 and -1 are picked for the initial entries in Table FPER because in two's complement arithmetic neither number is likely to occur as an end result of the exclusive-or comparison.

With respect to the variable parameters, an exclusive-or comparison is made of the entries in Tables VPCR and VPVD, with the result stored in Table VPER. For the variable parameters the pointer registers VPV and VPE are set such that data for the same time interval are compared. Pointer register VPE is also set such that the comparison result is entered in Table VPER on the line corresponding to the entry in Table VPVD. Figure 31 shows the status of the eight data tables and pointer registers at the end of the processing of the doppler data in the third 2-minute message.

FIXED PARAMETER CURRENT WORD (FPCR)	FIXED PARAMETER MAJORITY VOTED WORD (FPVO)	FIXED PARAMETER ERROR WORD (FPER)	VARIABLE PARAMETER CURRENT WORD (VPCR)	VARIABLE PARAMETER MAJORITY VOTED WORD (VPVD)	VARIABLE PARAMETER ERROR WORD (VPER)	DOPPLER WORD (DOPS)	REFRACTION WORD (REFS)
t_p 16223	t_p 16000	16416 VPR	T_0-4 16366	T_0-6 16143	16306 ← FPR	16063 ← FPV	16113
16224	16001	16417 FPE	16367	16144	16307	16064 N_1	16114 R_1
16225	16002	16420	16370	16145	16310	16065	16115
η 16226	η 16003	16421	T_0-2 16371	T_0-4 16146 ← VPV	16311 ← VPE	16066 ← DG4	16116 ← RE-1
16227	16004	16422	16372	16147	16312	16067	16117
16230	16005	16423	16373	16150	16313	16070	16120
ω_0 16231	ω_0 16006	16424	T_0 16374	T_0-2 16151	16314	16071	16121
16232	16007	16425	16375	16152	16315	16072	16122
16233	16010	16426	16376	16153	16316	16073	16123
$\dot{\omega}$ 16234	$\dot{\omega}$ 16011	16427	T_0+2 16377	T_0 16154	16317	16074	16124
16235	16012	16430	16400	16155	16320	16075	16125
16236	16013	16431	16401	16156	16321	16076	16126
ϵ 16237	ϵ 16014	16432	T_0+4 16402	T_0+2 16157	16322	16077	16127
16240	16015	16433	16403	16160	16323	16100	16130
16241	16016	16434	16404	16161	16324	16101	16131
A_0 16242	A_0 16017	16435	T_0+6 16405	T_0+4 16162	16325	16102	16132
16243	16020	16436	16406	16163	16326	16103	16133
16244	16021	16437	16407	16164	16327	16104	16134
Ω_0 16245	Ω_0 16022	16440	T_0+8 16410	T_0+6 16165	16330	16105	16135
16246	16023	16441	16411	16166	16331	16106	16136
16247	16024	16442	16412	16167	16332	16107	16137
$\dot{\Omega}$ 16250	$\dot{\Omega}$ 16025	16443	T_0+10 16413	T_0+8 16170	16333	16110	16140
16251	16026	16444	16414	16171	16334	16111	16141
16252	16027	16445	16415	16172	16335	16112	16142
Ci 16253	Ci 16030	16446		16173	16336		
16254	16031	16447		16174	16337		
16255	16032	16450		16175	16340		
Λ_G 16256	Λ_G 16033	16451		16176	16341		
16257	16034	16452		16177	16342		
16260	16035	16453		16200	16343		
16261	16036	16454		16201	16344		
16262	16037	16455		16202	16345		
16263	16040	16456		16203	16346		
16264	16041	16457		16204	16347		
16265	16042	16460		16205	16350		
16266	16043	16461		16206	16351		
Si 16267	Si 16044	16462		16207	16352		
16270	16045	16463		16210	16353		
16271	16046	16464		16211	16354		
16272	16047	16465		16212	16355		
16273	16050	16466		16213	16356		
16274	16051	16467		16214	16357		
16275	16052	16470		16215	16360		
16276	16053	16471		16216	16361		
16277	16054	16472		16217	16362		
16300	16055	16473		16220	16363		
16301	16056	16474		16221	16364		
16302	16057	16475		16222	16365		
16303	16060	16476					
16304	16061	16477					
16305	16062	16500					

FPCR (16223–16305): Contains 17 fixed parameters from second two-minute message in BCDX3 format

FPVO (16000–16062): Contains 17 fixed parameters from first two-minute message in BCDX3 format

FPER (16416–16500): BCD −1

VPCR (16366–16415): Contains 8 Variable parameters from second two-minute message in BCDX3 format

VPVD (16143–16172): Contains 8 variable parameters from first two-minute message in BCDX3 format; (16173–16222): BCD Zero

VPER (16306–16335): BCD −1; (16336–16365): BCD −2

DOPS (16066–16112): BCDX3 Zero

REFS (16116–16142): BCDX3 Zero

Fig. 30 STATUS OF DATA TABLES AND POINTER REGISTERS AT END OF SECOND TWO-MINUTE MESSAGE

Table 6

Summary of Changes in Major Counters, Registers, Flags, and Switches During the Second 2-Minute Message

Name	Mnemonic	Action
Orbital Word Counter	WORD	Same as for first 2-minute message.
Receiver Interrupt Flag	RCFG	
Program Clock Register	CLOC	
Sync Time Register	SYNC	
Interrupt Count Switch	INTC	Set in subroutines DP1, RF1, and MG1: reset in first execution of subroutine COLL, set in second execution of subroutine COLL.
Message Sync Flag	FDOP	No change.
Receiver Index Counter	XREC	Incremented in each execution of subroutines DP1 and DP2, then set to zero at end of DP2. Incremented in each execution of subroutines RF1 and RF2, then set to zero at end of RF2. Incremented in each execution of subroutines MG1 and MG2, then set to zero at end of MG2.
Majority Vote Counter	MJV1	Initialized to zero; incremented in subroutine VALI.
Message Counter	MSCT	Initialized to zero; incremented in subroutine UPTB.

FIXED PARAMETER CURRENT WORD (FPCR)	FIXED PARAMETER MAJORITY VOTED WORD (FPVD)	FIXED PARAMETER ERROR WORD (FPER)	VARIABLE PARAMETER CURRENT WORD (VPCR)	VARIABLE PARAMETER MAJORITY VOTED WORD (VPVD)	VARIABLE PARAMETER ERROR WORD (VPER)	DOPPLER WORD (DOPS)	REFRACTION WORD (REFS)
t_p 16223 ← FPR	t_p 16000 ← FPV	16416 ← FPE	T_0-4 16366 ← VPR	T_0-6 16143	16306 BCD −1	16063 N_1	16113
16224	16001	16417	16367	16144	16307	16064	16114 R_1
16225	16002	16420	16370	16145	16310	16065	16115
η 16226	η 16003	16421	T_0-2 16371	T_0-4 16146	T_0-4 diff 16311	16066 N_2	16116 ← RE-1
16227	16004	16422	16372	16147	16312	16067	16117
16230	16005	16423	16373	16150	16313	16070	16120
ω_0 16231	ω_0 16006	16424	T_0 16374 Contains 8 variable parameters from second two minute message in BCDX3 format	T_0-2 16151 ← VPV	T_0-2 diff 16314 ← VPE	16071 ← D04	16121
16232	16007	16425	16375	16152	16315	16072	16122
16233	16010	16426	16376	16153 Contains 8 variable parameters from first two-minute message in BCDX3 format	16316	16073	16123
$\dot{\omega}$ 16234	$\dot{\omega}$ 16011	16427	T_0+2 16377	T_0 16154	T_0 diff 16317 Contains exclusive or differences between Tables VPCR and VPVD	16074	16124
16235	16012	16430 Contains exclusive or differences between Tables FPCR and FPVD; zero value means no difference i.e. if the entry in location 16223 is the same as the entry in location 16000 then the entry in location 16416 is zero	16400	16155	16320	16075	16125 BCD Zero
16236	16013	16431	16401	16156	16321	16076	16126
ϵ 16237	ϵ 16014	16432	T_0+4 16402	T_0+2 16157	T_0+2 diff 16322	16077 BCD Zero	16127
16240	16015	16433	16403	16160	16323	16100	16130
16241	16016	16434	16404	16161	16324	16101	16131
A_0 16242	A_0 16017	16435	T_0+6 16405	T_0+4 16162	T_0+4 diff 16325	16102	16132
16243	16020	16436	16406	16163	16326	16103	16133
16244 Contains 17 fixed parameters from second two-minute message in BCDX3 format	16021 Contains 17 fixed parameters from first two-minute message in BCDX3 format	16437	16407	16164	16327	16104	16134
Ω_0 16245	Ω_0 16022	16440	T_0+8 16410	T_0+6 16165	T_0+6 diff 16330	16105	16135
16246	16023	16441	16411	16166	16331	16106	16136
16247	16024	16442	16412	16167	16332	16107	16137
$\dot{\Omega}$ 16250	$\dot{\Omega}$ 16025	16443	T_0+10 16413	T_0+8 16170	T_0+8 diff 16333	16110	16140
16251	16026	16444	16414	16171	16334	16111	16141
16252	16027	16445	16415	16172	16335	16112	16142
C_i 16253	C_i 16030	16446		16173	16336		
16254	16031	16447		16174	16337		
16255	16032	16450		16175	16340		
Λ_G 16256	Λ_G 16033	16451		16176	16341		
16257	16034	16452		16177	16342		
16260	16035	16453		16200	16343		
16261	16036	16454		16201	16344		
16262	16037	16455		16202	16345		
16263	16040	16456		16203	16346		
16264	16041	16457		16204	16347 BCD −2		
16265	16042	16460		16205 BDC Zero	16350		
16266	16043	16461		16206	16351		
S_i 16267	S_i 16044	16462		16207	16352		
16270	16045	16463		16210	16353		
16271	16046	16464		16211	16354		
16272	16047	16465		16212	16355		
16273	16050	16466		16213	16356		
16274	16051	16467		16214	16357		
16275	16052	16470		16215	16360		
16276	16053	16471		16216	16361		
16277	16054	16472		16217	16362		
16300	16055	16473		16220	16363		
16301	16056	16474		16221	16364		
16302	16057	16475		16222	16365		
16303	16060	16476					
16304	16061	16477					
16305	16062	16500					

Fig. 31 STATUS OF DATA TABLES AND POINTER REGISTERS AT END OF DOPPLER WORD IN THIRD TWO-MINUTE MESSAGE

During the fourth 2-minute message the content of Tables FPER and VPER will again be examined in subroutine VALI (Fig. A-9). If the entry on any given line of these tables is zer . the corresponding lines of Tables FPCR and FPVD (or VPCR and VPVD) agree and hence the line in Table FPVD (or VPVD) contains valid, majority-voted data.

Alternatively if the entry on any given line of Tables FPER and VPER is not zero, validation is to be performed as follows:

(a) An exclusive-or comparison is made between the entries in Tables FPCR and FPVD (or VPCR and VPVD), with the result placed temporarily in a result register. At this point in the fourth 2-minute message Tables FPCR and VPCR contain the data from the third 2-minute message. Tables FPVD and VPVD contain data from the first 2-minute message. Tables FPER and VPER contain the results of the exclusive-or comparison on data from the first and second messages.

(b) A logical-and operation is now made on the results of the two exclusive-or operations with the result replacing the previous result in the result register. Inasmuch as a logical-and operation results in a one bit for each two bits that are one bit and a zero bit otherwise, the word in the result register reflects differences between the word in the first message and the words in both the second and third messages.

(c) The result of the logical-and operation is then exclusive-or'ed with the validated table word to complement the bits in error, and the error table entry is set to the new error pattern. This process will continue until there is a zero error result.

Figure 32 summarizes the validation process using as example the entry 100 011 010 001, or (in octal notation) 4321$_{(8)}$. The example assumes that in the first 2-minute message this entry is received as 5321$_{(8)}$, in the

STEP	CURRENT WORD	RESULT WORD	MAJORITY VOTED WORD	ERROR WORD
1. STATUS AFTER INITIALIZATION	000 000 000 000	--- --- --- ---	000 000 000 000	111 111 111 110
2. STATUS AFTER EXECUTION OF SUBROUTINE VALI IN SECOND 2-MINUTE MESSAGE	101 011 010 001	--- --- --- ---	101 011 010 001	111 111 111 111
3. STATUS AFTER EXECUTION OF SUBROUTINE VALI IN THIRD 2-MINUTE MESSAGE	100 011 011 001	--- --- --- ---	101 011 010 001	001 000 001 000
4. STATUS AT BEGINNING OF SUBROUTINE VALI IN FOURTH 2-MINUTE MESSAGE	100 100 010 001	--- --- --- ---	101 011 010 001	001 000 001 000
4a. VALID + CURRENT	100 100 010 001	001 111 000 000	101 011 010 001	001 000 001 000
4b. RESULT · ERROR	100 100 010 001	001 000 000 000	101 011 010 001	001 000 001 000
4c. RESULT + ERROR	100 100 010 001	100 011 010 001	100 011 010 001	000 000 000 000

Fig. 32 SUMMARY OF VALIDATION PROCEDURE

second 2-minute message as $4331_{(8)}$, and in the third 2-minute message as $4421_{(8)}$. After initialization (step 1) processing of the entry is done in the second, third, and fourth messages with the results shown in Fig. 32 in Steps 2, 3, and 4, respectively. The values of -2 and -1 shown in the error word column entries for steps 1 and 2, respectively, are in two's complement format.

After a majority vote is reached for the data on any particular line in Tables FPVD and VPVD, new data read into the corresponding entry in Tables FPCR and VPCR during subsequent 2-minute messages are discarded

TWO-MINUTE MESSAGES NOS. 5-9

The above procedures are repeated for 2-minute messages Nos. 5-9 such that at the end of the ninth message the data tables will appear as shown in Fig. 33, and the check on the number of doppler counts in subroutine IDLE will transfer program control to subroutine NAV. Before discussion of this subroutine, two situations that can affect the real-time program are discussed. These two situations are loss of lock and injection during a pass.

MESSAGE DEVIATIONS

Loss of Lock

A system requirement is that the relative time associated with a 2-minute interval and a particular variable parameter data set be known, i. e., the actual time that a doppler counting interval spans and the associated set of variable parameters for that 2-minute interval.

Time synchronization of doppler data is accomplished by making use of satellite time. The satellite transmits a sync word every 2 minutes at an integral universal 2-minute time. This sync word time determines the doppler counting interval. However, if a receiver loses lock

FIXED PARAMETER CURRENT WORD (FPCR)	FIXED PARAMETER MAJORITY VOTED WORD (FPVD)	FIXED PARAMETER ERROR WORD (FPER)	VARIABLE PARAMETER CURRENT WORD VPCR)	VARIABLE PARAMETER MAJORITY VOTED WORD (VPVD)	VARIABLE PARAMETER ERROR WORD (VPER)	DOPPLER WORD (DOPS)	REFRACTION WORD (REFS)
t_p 16223	t_p 16000	16416	T_0+10 16366	T_0-6 16143	16306 BCD	16063	16113
16224	16001	16417	16367	16144	16307 −1	16064 N_1	16114 R_1
16225	16002	16420	16370	16145	16310	16065	16115
η 16226	η 16003	16421	T_0+12 16371	T_0-4 16146	16311	16066	16116
16227	16004	16422	16372	16147	16312	16067 N_2	16117 R_2
16230	16005	16423	16373	16150	16313	16070	16120
ω_0 16231	ω_0 16006	16424	T_0+14 16374	T_0-2 16151	16314	16071	16121
16232	16007	16425	16375	16152	16315	16072 N_3	16122 R_3
16233	16010	16426	16376	16153	16316	16073	16123
$\dot{\omega}$ 16234	$\dot{\omega}$ 16011	16427	T_0+16 16377	T_0 16154	16317	16074	16124
16235	16012	16430	16400	16155	16320	16075 N_4	16125 R_4
16236	16013	16431	16401	16156	16321	16076	16126
ϵ 16237	ϵ 16014	16432	T_0+18 16402	T_0+2 16157	16322	16077	16127
16240	16015	16433	16403	16160	16323	16100 N_5	16130 R_5
16241	16016	16434	16404	16161	16324	16101	16131
A_0 16242	A_0 16017	16435	T_0+20 16405	T_0+4 16162	16325	16102	16132
16243	16020	16436	16406	16163	16326	16103 N_6	16133 R_6
16244	16021	16437	16407	16164	16327	16104	16134
Ω_0 16245	Ω_0 16022	16440	T_0+22 16410	T_0+6 16165	16330	16105	16135
16246	16023	16441	16411	16166	16331	16106 N_7	16136 R_7
16247	16024	16442	16412	16167	16332	16107	16137
$\dot{\Omega}$ 16250	$\dot{\Omega}$ 16025	16443	T_0+24 16413	T_0+8 16170	16333	16110	16140
16251	16026	16444	16414	16171	16334	16111 N_8	16141 R_8
16252	16027	16445	16415	16172	16335	16112	16142
Ci 16253	Ci 16030	16446		T_0+10 16173	16336		
16254	16031	16447		16174	16337		
16255	16032	16450		16175	16340		
ΛG 16256	ΛG 16033	16451		T_0+12 16176	16341		
16257	16034	16452		16177	16342		
16260	16035	16453		16200	16343		
16261	16036	16454		T_0+14 16201	16344		
16262	16037	16455		16202	16345		
16263	16040	16456		16203	16346		
16264	16041	16457		T_0+16 16204	16347		
16265	16042	16460		16205	16350		
16266	16043	16461		16206	16351		
Si 16267	Si 16044	16462		T_0+18 16207	16352		
16270	16045	16463		16210	16353		
16271	16046	16464		16211	16354		
16272	16047	16465		T_0+20 16212	16355		
16273	16050	16466		16213	16356		
16274	16051	16467		16214	16357		
16275	16052	16470		T_0+22 16215	16360		
16276	16053	16471		16216	16361		
16277	16054	16472		16217	16362		
16300	16055	16473		T_0+24 16220	16363 BCD		
16301	16056	16474		16221	16364 −1		
16302	16057	16475		16222	16365		
16303	16060	16476					
16304	16061	16477					
16305	16062	16500					
Contains 17 fixed parameters from the ninth two-minute message in BCDX3 format	Contains 17 fixed parameters in BCDX3 format; the data in a given location are majority voted if the corresponding location in Table FPER is zero	Contains all zeros except where no majority vote was reached	Contains 8 variable words from the ninth two-minute message in BCDX3 format	Contains the variable parameters in BCDX3 format, the data in a given location are majority voted if the corresponding location in Table VPER is zero	Contains all zeros except where no majority vote was reached		

Fig. 33 STATUS OF DATA TABLES AT END OF NINTH TWO-MINUTE MESSAGE

from the satellite during a particular interval, doppler counting discontinues until lock is regained and the receiver regains satellite time sync. One or more doppler counts can be lost during this time. Once lock is regained, it is the responsibility of the computer program to locate the right time slot for the doppler data.

This is also true for the variable parameter data, since time dependent variable parameter data precess through the message set one satellite word every 2 minutes; i.e., at the end of transmission of one 2-minute interval of data in the variable parameter portion, parameter 2 becomes parameter 1, 3 becomes 2, 4 becomes 3, etc., and a new parameter replaces parameter 8. For the purpose of real-time validation it is required that a variable parameter set be referenced to the correct relative time interval.

A programmed counter can be used to detect missing doppler counts and thereby use the occurrence or detected nonoccurrence of doppler data to update table storage addresses. A method for accomplishing this function is as follows:

If the receiver loses lock on the satellite signal, interrupt flag RCFG will not be set, and the program will continue to dwell in subroutine IDLE, with time being incremented in subroutine INCR and the 2-minute elapsed test being made in subroutine TES2 (Fig. A-8). When the contents of registers SYNC and CLOC become equal, 2 minutes have elapsed and subroutine TES2 will check doppler flag DPFG to determine if valid doppler data have been received. If loss of lock occurred before valid doppler data have been received, then the doppler flag will not have been set and the table updating done in subroutine DP2 will not have been executed. In subroutine TES2 the finding that the doppler flag has not been set will direct transfer of program control to subroutine UPTB.

Subroutine UPTB (Fig. A-7) is executed as previously described with message count register MSCT being incremented as before. This result will cause the pointer register for Tables VPVD, VPER, DOPS, and REFS to skip over

the table positions where the missing data would have been. For this reason the initialization entries in Tables DOPS and REFS are selected to be the correct entries for missing data. Return is made to subroutine TES2, which directs transfer to subroutine RESE.

Subroutine RESE (Fig. A-7) resets internal program clock register CLOC to zero to mark the beginning of the 2-minute interval and sets register SYNC to a value of 2 minutes to mark the time of the next 2-minute interval. Program control then returns through subroutine TES2 to subroutine IDLE where the routine repeats as described above until the operator terminates the collection of real-time data from the receiver, or until the next receiver interrupt occurs.

Injection During Pass

The test to determine if an injection has been made during the pass occurs in subroutine INJT to which transfer is made during subroutine VALD (Fig. A-8).

Subroutine INJT (Fig. A-9) checks whether two or more 2-minute messages have been received. If they have, a comparison is made between the times of perigee in the two messages, which will be in Tables FPCR and FPVD. Inasmuch as the satellite message is updated by the ground injection station twice per day at approximately 12-hour intervals, the change in the value of perigee time in the two messages will yield a bit difference of 6 or greater, if an injection has occurred. If an injection has occurred, a test will then be made on majority vote count register MJV1 to determine how many majority-voted, valid messages have been received. If three or more valid messages have been obtained, sufficient data are already available for use in the fix calculations and return is made to subroutine VALD.

If the number of valid messages is less than three, there will not be a sufficient amount of data available to complete the majority vote process because the satellite is

transmitting an updated message and no further data from the old message will be obtained. This result directs that Tables FPER and VPER be reset to -2 again so that the majority vote process may be conducted with the updated message, and return is made to subroutine VALD.

An alternative method for detecting injection uses satellite words 140, 146, or 152. At the time of an injection these words are transmitted with a value of binary zero. This method has the disadvantage that it is not reliable if the receiver loses lock during injection.

SUBROUTINE NAV

Determine Validity of Variable Parameters

Returning to subroutine NAV (Fig. A -1) the first operation is a check to determine if any of the entries in variable parameter majority voted word Table VPVD did not pass the majority vote test. For this operation, program control passes to subroutine VPTS.

Subroutine VPTS (Fig. A-12) begins by summing the three lines in variable parameter majority voted word Table VPER corresponding to the entry for the time interval 2 minutes before sync time (T_o -2). If the sum is zero the three lines in variable parameter majority voted word Table VPVD for T_o -2 are valid data. The subroutine repeats until all the variable data received in the interval from 2 minutes before sync time through 18 minutes after sync time are examined.

Assume now, for example, that the entry for a 2-minute entry, say T_o +4, did not pass the majority vote test, i.e., the sum of the entries in Table VPER for the three transfers is not zero. Subroutine VPTS sets the three lines in variable parameter majority voted word Table VPVD for the entry T_o +4 to a value of binary zero and also sets the two doppler words N_1 and N_2 (i.e., the two doppler words centered on time T_o +4) to a value of BCDX3 zero. Deleting these two doppler words minimizes

the error in the portion of the navigation mathematic routines in which the differences in the actual and theoretical satellite positions at this time are determined.

The program concludes by discarding the variable data for the intervals for which the data are not received three times (i.e., those prior to T_0-2 and after T_0 +18), and program control then returns to subroutine NAV.

Punch Majority Voted Data, Doppler Data, and Refraction Data on Tape

The next operation in subroutine NAV is to punch a tape for the majority voted data, the doppler data, and the refraction data. For this operation, control passes to subroutine PTAP.

Subroutine PTAP (Fig. A-11), using subroutines PROC and PRNT, causes the 17 fixed parameter majority voted words, the 11 variable parameter majority voted words for the 2-minute intervals from T_0 -2 through T_0 +18, the eight doppler words, and the eight refraction words to be printed out on the teletypewriter in ASCII format and also punched on tape in ASCII format. Program control then returns to subroutine NAV.

Convert Fixed Parameters, Doppler Data, and Refraction Data to Floating Point Format

The next operation in subroutine NAV is to convert the fixed parameters, doppler data, and refraction data to floating point format. For this operation program control passes to subroutine FMTT.

Subroutine FMTT (Fig. A-14) converts the fixed parameters, doppler data, and refraction data from BCDX3 format to BCD format and then to floating point format. With respect to the fixed parameters, Table 2 shows that the coding of the most significant digit in the value for time of perigee differs from the coding of the most significant digit in the values for the remainder of the fixed parameters.

A test is made in subroutine FMTT therefore to locate time of perigee and convert the first character from the coded value in Table 2 to the conventional BCD value. In addition, all the data are treated as integer values; i.e., it is assumed that each value is multiplied by the proper power of 10 to make it an integer.

For example, time of perigee, i.e., the first fixed parameter received from the satellite, is a number consisting of four integer places and five fractional places. The configuration of the number is thus XXXX.XXXXX. For purposes of the conversion from BCD to floating point it is assumed that this number is multiplied by 10^5, thus making it an integer. Later in the navigation math routines the value of time of perigee will be multiplied by 10^{-5} to give it its proper scaling again. The advantage of this process is that a straightforward BCD to binary routine can be used in subroutine FMTT which does not have to account for the scaling of the various parameters. Later in the navigation mathematical routines these scalings can be accounted for very easily.

Program control returns to subroutine NAV.

Convert Variable Parameters to Floating Point Format

The next step in subroutine NAV is to convert the variable parameters from BCDX3 format to BCD format and then to binary floating point format. Next the variable data for each 2-minute entry are separated into their constituent components, i.e., the out-of-plane component (η), the correction (ΔE) to the eccentric anomaly, and the correction (ΔA) to the mean semimajor axis. Program control transfers to subroutine VPMC.

Subroutine VPMC (Fig. A-14) begins by checking the variable parameter entries in Table VPVD to determine if they are binary zero (see section on Subroutine NAV). If they are, the program makes no change in their value. If they are not, the program converts the data from BCDX3 to BCD.

Next the value of the out-of-plane term is extracted from its location in the third transfer of each of the variable parameters. The out-of-plane term is reconverted to BCDX3 format and then checked in subroutine BCXS (Fig. A-7) to determine if it is a legal BCDX3 character. If the term is a legal BCDX3 character it will be reconverted to BCD, formatted to binary floating point, and stored. If it is an illegal BCDX3 character the term is also formatted to binary floating point and stored, but as a negative value. The negative value will be used to delete the illegal data during the navigation mathematical routines.

The program next converts the data for the correction (ΔA) to the mean semimajor axis and the correction (ΔE) to the eccentric anomaly into binary floating point.

Lock-on (T_0) time is next converted to binary floating point and the program returns to subroutine NAV.

Collect Navigator's Estimates

The next step in subroutine NAV is to collect the navigator's estimates of sync time, position, antenna height, heading (course), rate (speed), day number of pass, and the day numbers of the period for which alerts are desired. Program control transfers to subroutine POSI.

Subroutine POSI (Fig. A-15) requests the navigator to enter the estimates in the format shown in Table 3. The program reformats the data as shown on Fig. A-15 and stores them for use in the navigation math routines, described in Sections 7 and 8. These navigation math routines will follow immediately, unless the navigator terminates the program. Before the math routines are discussed, however, the modifications to the real-time data processing procedures to allow their use in nonreal-time, or off-line postpass data processing, will be described.

NONREAL-TIME DATA PROCESSING

Nonreal-time data processing is done if the navigator wishes to renavigate the pass data or if he wishes to execute the navigation math routines using pass data collected at a previous time. The data may be in the form of punched tape prepared as described in the previous section or may be a manual input from the teletypewriter. To select the nonreal-time option the navigator sets the appropriate switch on the computer console (SW2 in the example shown in Fig. A-1). The navigator may also elect to prepare a punched tape by setting another switch (SW4 in the example shown in Fig. A-1) on the computer console.

The program (Fig. A-1) is executed as described in Section 6. In the test for interrupt, subroutine INP3 will find SW2 set and transfer control to subroutine ESM.

Subroutine ESM (Fig. A-1) begins by transferring program control to subroutine READ.

Subroutine READ (Fig. A-10) directs the navigator to enter the fixed and variable parameters, the doppler data, and the refraction data either as punched tape or manually through the teletypewriter keyboard in ASCII format.

As each group of nine characters is entered, subroutine INPU (Fig. A-13) converts the entry to BCDX3 format and stores it in the appropriate locations in Tables FPVD, VPVD, DOPS, and REFS.

Depending on the setting of SW4, program control will transfer to either subroutine PTAP or to subroutine FMTT and the sequence described in Section 6 is repeated.

7. THREE-VARIABLE NAVIGATION

METHOD OF SOLUTION

At this point validated satellite orbital data are available and arranged in tables in accordance with the procedures described in Section 6. The doppler and ionospheric refraction data have also been assembled in tables. The variable parameters, the doppler data, and the ionospheric refraction data are time-ordered by 2-minute intervals. The navigator's estimates and the program constants are given in Tables 3 and 4, respectively. A three-variable fix is obtained using these data by a least squares minimization of the residuals formed by differencing the measured and theoretical slant range changes. The solution is an iterative process in which each iteration results in a correction to the navigator's latitude ($\Delta\varphi$), longitude ($\varphi\lambda$), and frequency offset (Δf). Successive iterations produce smaller corrections, and the fix is obtained when these corrections become smaller than predefined breakout constants.

Figure 34 diagrams the steps followed to obtain the navigation fix. These steps are divided into five parts to (1) set up input data, (2) perform initial noniterative computations, (3) solve for the fix by least squares minimization in an iterative process, (4) edit the doppler data preparatory to a repetition of the iterative fix procedures, and (5) calculate alerts.

Input Data

The setting up of input data for the navigation solution computations consists of correcting the 400-MHz doppler data for the effects of ionospheric refraction, setting up the navigator's table of relative position motion, computing the time of the first fiducial point (sync time), setting up the table of out-of-plane orbit corrections at 4-minute intervals, and interpolating for the corrections at 2-minute intervals. In addition a determination is made of

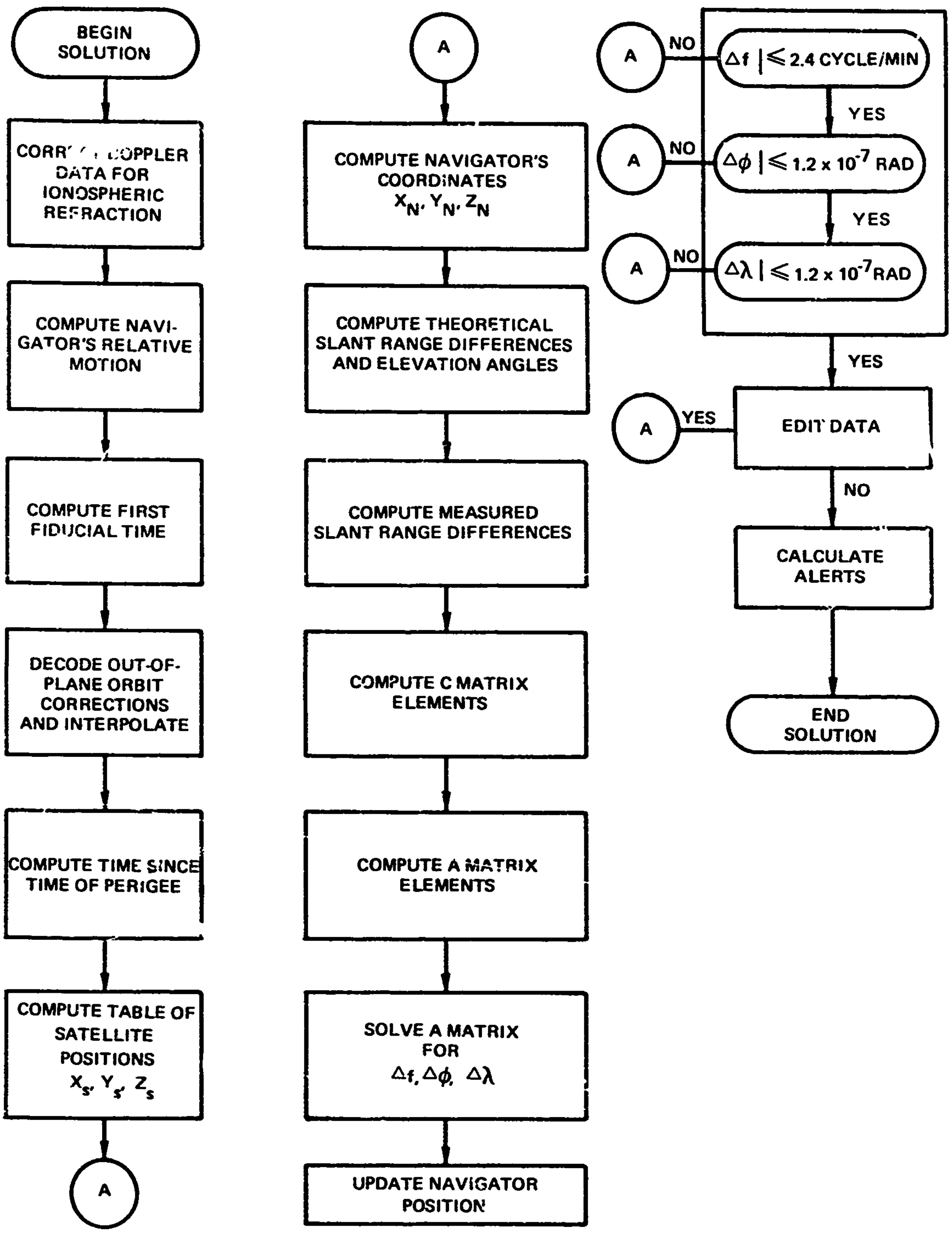


Fig. 34 BLOCK DIAGRAM OF NAVIGATION SOLUTION

which doppler intervals must not be considered in the navigation solution.

Preliminary Computations

Preliminary computations for the navigation solution which are not in the iterative process (i.e., need only be performed once per fix computation) consist of computing the satellite X, Y, Z positions (earth center fixed inertial coordinates) for each interval of the pass.

Iteration

The iterative process consists of eight steps to be executed in order for each iteration. These steps are as follows:

1. Compute navigator's X, Y, Z positions (earth center fixed inertial coordinates) for each interval of the pass.

2. Compute the theoretical slant range differences from the navigator and satellite X, Y, Z coordinates, compute the partial derivatives of slant range differences with respect to φ and λ, and compute the elevation angles of the satellite with respect to the navigator.

3. Compute measured slant range differences from the values of cycle count for each interval of the pass.

4. Set up C matrix where each row of C is an interval and the elements are:

C_{I0} = slant range difference residual,

C_{I1} = constant function of ground frequency vacuum wavelength,

C_{I2} = derivative of slant range difference with respect to φ, and

C_{I3} = derivative of slant range difference with respect to λ.

5. Reduce the C matrix to a 3 × 3 A matrix by taking $C^T \cdot C \cdot \Delta = C^T \cdot c$, where C^T is the transpose of C, thus getting:

$$- a_{10} + a_{11} \Delta f + a_{12} \Delta\varphi + a_{13} \Delta\lambda = 0,$$

$$- a_{20} + a_{21} \Delta f + a_{22} \Delta\varphi + a_{23} \Delta\lambda = 0, \text{ and}$$

$$- a_{30} + a_{31} \Delta f + a_{32} \Delta\varphi + a_{33} \Delta\lambda = 0.$$

6. By Cramer's rule of determinant solution, solve for Δf, $\Delta\varphi$, and $\Delta\lambda$.

7. Update each of the navigator's estimated positions by:

$$\varphi_{i+1} = \varphi_i + \Delta\varphi_i \text{ and}$$

$$\lambda_{i+1} = \lambda_i + \Delta\lambda_i ,$$

where i is the iteration number.

8. Determine if the values of $\Delta\varphi$, $\Delta\lambda$, Δf are below predefined breakout constants. If so, then the fix is obtained. If not, repeat the iterative process. Breakout constants are chosen as:

$$\Delta\varphi \leq 1.2 \times 10^{-7} \text{ rad,}$$

$$\Delta\lambda \leq 1.2 \times 10^{-7} \text{ rad, and}$$

$$\Delta f \leq 2.4 \text{ cycle/minute.}$$

Data Editing

If doppler data have been collected during more than four 2-minute intervals, fix accuracy is improved by editing the doppler data such that intervals with elevation angles less than 7.5° are deleted from the calculations. After deletion of the low elevation doppler data the steps of the iterative process are repeated.

Alert Calculations

The alert computations described here have been designed to minimize computer memory requirements above those required for the position fix computation by repeating several of the steps used in the fix computation.

The procedure to be used is as follows:

1. Compute satellite coordinates at a future time T.
2. Compute navigator's coordinates at time T.
3. Compute elevation angle
   a. If positive a satellite pass is underway,
   b. If negative a satellite pass is not underway.
4. Increment time T and repeat Steps 1-3.
5. Repeat Steps 1-4 until all desired alerts have been generated.

SOLUTION FOR NAVIGATION FIX AND ALERT CALCULATIONS

In the following solution, the equation shown for refraction correction (Step A. 3) is for the ITT equipment, as given in Eq. (6). If the Magnavox equipment is used, Step A should be modified to incorporate Eq. (7).

STEP A — Correct 400-MHz doppler counts for effect of ionospheric refraction.

INPUTS: $N_{k_{400}}$ - Table of measured 400-MHz doppler counts from ITT SRN-9 receiver (cycles).

R_k - Table of measured refraction counts from ITT SRN-9 receiver (cycles).

KM - Number of fiducial times during the time from the first fiducial time and spanning the interval for which the $N_{k_{400}}$ doppler counts were received.

KM-1 - Number of cycle counts.

The following equations shall be executed for each value of k (k = 1, 2, 3, ---, KM-1):

$$\text{If } N_{k_{400}} \leq 2 \times 10^6,\ N_k = 0, \text{ otherwise continue.} \quad (A.1)$$

$$\text{If } R_k = 2 \times 10^3,\ N_k = 0, \text{ otherwise continue.} \quad (A.2)$$

$$N_k = N_{k_{400}} + \frac{24}{55}(2000 - R_k). \quad (A.3)$$

OUTPUTS: N_k - Table of refraction corrected "vacuum" doppler counts (cycles).

NDOP - Number of nonzero doppler counts in N_k table.

STEP B — Compute navigator's relative motion in latitude and longitude.

INPUTS φ_e, λ_e - Navigator's estimate of his position (radians).

d - Navigator's heading at estimated first fiducial time (radians clockwise from true north).

v - Speed at estimated first fiducial time (knots).

KM - Number of fiducial times during the time from the first fiducial time and spanning the interval for which the doppler counts were received.

f - Flattening of reference ellipsoid.

The following computations shall be performed for each value of k (k = 1, 2, 3, ---, KM):

$$\delta = f(2-f) \tag{B.1}$$

$$\Delta\lambda_k = (k-1)\, v \frac{\sin d}{\cos\varphi_e} \left[\frac{1}{3443.934}\ \frac{2}{1}\ \frac{1}{60}\right] \left[1 - 0.5\delta \sin^2\varphi_e\right] \tag{B.2}$$

$$\Delta\varphi_k = (k-1)\, v \cos d \left[\frac{1}{3443.934}\ \frac{2}{1}\ \frac{1}{60}\right] \left[1 + \delta(1 - 0.5\delta \sin^2\varphi_e\right] \tag{B.3}$$

<u>OUTPUT</u>: $\Delta\varphi_k$, $\Delta\lambda_k$ - Table of navigator's relative motion in latitude ($\Delta\varphi$) and longitude ($\Delta\lambda$) at 2-minute intervals (radians).

<u>STEP C</u> — Compute first fiducial time.

<u>INPUTS</u>: T_c - Navigator's estimate for first fiducial time (minutes GMT).

t_0 - Two-minute interval number from first variable parameter in satellite message.

$$K' = \left[\frac{T_c}{2}\right] \quad [\,]\ \text{means integer part of} \tag{C.1}$$

$$I = 2K' \tag{C.2}$$

$$T_c' = \left[\frac{I}{30}\right] \tag{C.3}$$

$$J = I - 30\, T_c' \tag{C.4}$$

$$H = 2\, t_0 - J \tag{C.5}$$

$$T_0 = I + H - 30 \left[\frac{H}{15}\right] \tag{C.6}$$

<u>OUTPUT</u>: T_0 - First fiducial time (minutes).

<u>STEP D</u> — Decode out-of-plane orbit corrections and interpolate for missing corrections.

<u>INPUTS</u>: T_0 - First fiducial time (minutes).

η_k - Table of up to 11 values (k = 1, 2, 3, ---, 11) from satellite message for reconstructing out-of-plane coordinates where each value is the BCD equivalent of the ninth digit of the corresponding variable parameter and η_1 is the variable corresponding to T_o - 2.

KM - Number of fiducial times, etc.

$$N = T_0 - 4\left[\frac{T_0}{4}\right] \quad [\;] \text{ means integer part of} \tag{D.1}$$

For positive values of η_k equations D. 3 through D.5 shall be executed for

$$k = 2, 4, 6, \text{---} \text{ if } N = 0 \text{ or for } k = 1, 3, 5, \text{---} \text{ if } N \neq 0. \tag{D.2}$$

For negative values of η_k, CP(ℓ) = 0 and CPT(ℓ) = k.

If $\eta_k - 5 \geq 0$ then

$$CP(\ell) = 100\,(\eta_k - 5) + 10\,\eta_{k+1} \tag{D.3}$$

and CPT (ℓ) = k.

If $\eta_k - 5 < 0$ and

$\eta_k \neq 0$ then

$$CP(\ell) = 100(\eta_k - 5) - 10\ \eta_{k+1} \tag{D.4}$$

and $CPT(\ell) = k.$

If $\eta_k - 5 < 0$ and

$\eta_k = 0$ then

$$CP(\ell) = -10\ \eta_{k+1} \tag{D.5}$$

and $CPT(\ell) = k$

where $\ell = 1, 2, 3, ---, OP.$

If $OP \leq 2$ then

$$\eta_k = 0 \text{ for } k = 1, 2, 3, ---, KM. \tag{D.6}$$

If OP = 3, execute Eq. (D. 7-a) for k = 1, 2, 3, ---, KM.

If OP = 4 and N = 0 execute Eq. (D. 7-a) for k = 1, 2, 3 and Eq. (D. 7-b) for k = 4, 5, 6, ---, KM.

If OP = 4 and N $\neq$ 0 execute Eq. (D. 7-a) for k = 1, 2 and Eq. (D. 7-b) for k = 3, 4, 5, ---, KM.

If OP = 5 and N = 0 execute Eq. (D. 7-a) for k = 1, 2, 3, Eq. (D. 7-b) for k = 4, 5, and Eq. (D. 7-c) for k = 6, 7, 8, ---, KM.

If OP = 5 and N $\neq$ 0 execute Eq. (D. 7-a) for k = 1, 2, 3, Eq. (D. 7-b) for k = 4, and Eq. (D. 7-c) for k = 5, 6, 7, ---, KM.

(D. 7)

$$\eta_k = \left[\frac{(K+1) - CPT(2)}{CPT(1) - CPT(2)} \cdot \frac{(K+1) - CPT(3)}{CPT(1) - CPT(3)}\right] CP(1) \quad (D.7\text{-a})$$

$$+ \left[\frac{(K+1) - CPT(1)}{CPT(2) - CPT(1)} \cdot \frac{(K+1) - CPT(3)}{CPT(2) - CPT(3)}\right] CP(2)$$

$$+ \left[\frac{(K+1) - CPT(1)}{CPT(3) - CPT(1)} \cdot \frac{(K+1) - CPT(2)}{CPT(3) - CPT(2)}\right] CP(3),$$

$$\eta_k = \left[\frac{(K+1) - CPT(3)}{CPT(2) - CPT(3)} \cdot \frac{(K+1) - CPT(4)}{CPT(2) - CPT(4)}\right] CP(2) \quad (D.7\text{-b})$$

$$+ \left[\frac{(K+1) - CPT(2)}{CPT(3) - CPT(2)} \cdot \frac{(K+1) - CPT(4)}{CPT(3) - CPT(4)}\right] CP(3)$$

$$+ \left[\frac{(K+1) - CPT(2)}{CPT(4) - CPT(2)} \cdot \frac{(K+1) - CPT(3)}{CPT(4) - CPT(3)}\right] CP(4),$$

$$\eta_k = \left[\frac{(K+1) - CPT(4)}{CPT(3) - CPT(4)} \cdot \frac{(K+1) - CPT(5)}{CPT(3) - CPT(5)}\right] CP(3) \quad (D.7\text{-c})$$

$$+ \left[\frac{(K+1) - CPT(3)}{CPT(4) - CPT(3)} \cdot \frac{(K+1) - CPT(5)}{CPT(4) - CPT(5)}\right] CP(4)$$

$$+ \left[\frac{(K+1) - CPT(3)}{CPT(5) - CPT(3)} \cdot \frac{(K+1) - CPT(4)}{CPT(5) - CPT(4)}\right] CP(5).$$

<u>OUTPUT</u>: η_k - Table of out-of-plane orbit components (meters) for k = 1, 2, 3, ---, KM.

<u>STEP E</u> — Compute time between time of perigee and first fiducial time.

<u>INPUTS</u>: T_0 - First fiducial time (minutes).

t_p - Time of satellite perigee from message (minutes).

n - Satellite mean motion (radians/minute).

$$t = T_0 - t_p \tag{E.1}$$

$$t_R = 1440 - 2\Pi/n \tag{E.2}$$

If $t \leq -480$ then $\Delta t_p = t + 1440.$ (E.3)

If $-480 < t < t_R$ then $\Delta t_p = t.$

If $t_R \leq t$ then $\Delta t_p = t - 1440.$

OU̲T̲PUT: Δt_p - Time between time of perigee and first fiducial time (minutes).

STEP F — Compute satellite coordinates at 2-minute intervals.

INPUTS: Δt_p - Time between time of perigee and first fiducial time (minutes).

KM - Number of positions to be computed.

- All satellite orbit parameters from message.

The following computations shall be performed for each value of k (k = 1, 2, 3, ---, KM):

$$\Delta t_k = \Delta t_p + 2\,(k - 1), \tag{F.1}$$

$$M_k = n\, \Delta t_k, \tag{F.2}$$

$$E_k = M_k + \epsilon \sin M_k + \Delta E_k, \quad \text{[assumes that } M_k, \Delta E_k, \text{ and } E_k \text{ are in radians]} \tag{F.3}$$

$$A_k = A_0 + \Delta A_k, \tag{F.4}$$

$$u_k = A_k (\cos E_k - \epsilon), \tag{F.5}$$

$$v_k = A_k (\sin E_k), \tag{F.6}$$

$$\omega_k = \omega_0 - \dot{\omega}\, \Delta t_k, \tag{F.7}$$

$$x'_k = u_k \cos \omega_k - v_k \sin \omega_k, \tag{F.8}$$

$$y'_k = u_k \sin \omega_k + v_k \cos \omega_k, \tag{F.9}$$

$$z'_k = \eta_k, \tag{F.10}$$

$$\beta_k = (\Omega_0 - \Lambda_G) + (\dot{\Omega} - \omega_e)\ \Delta t_k, \tag{F.11}$$

$$X_{Sk} = x'_k \cos \beta_k - y'_k \text{ Ci} \sin \beta_k + z'_k \text{ Si} \sin \beta_k, \tag{F.12}$$

$$Y_{Sk} = x'_k \sin \beta_k - y'_k \text{ Ci} \cos \beta_k - z'_k \text{ Si} \cos \beta_k, \text{ and} \tag{F.13}$$

$$Z_{Sk} = y'_k \text{ Si} + z'_k \text{ Ci}. \tag{F.14}$$

<u>OUTPUT</u>: X_{Sk}, Y_{Sk}, Z_{SK} – Satellite coordinates at the fiducial time points (meters).

<u>STEP G</u> – Compute navigator's coordinates and partial derivatives.

<u>INPUTS</u>: $\Delta\varphi_k$ - Table of navigator's relative motion in latitude at fiducial times (radians).

$\Delta\lambda_k$ - Table of navigator's relative motion in longitude at fiducial times radians).

φ_f, λ_f - Fix latitude and longitude (radians) (Note: Initial values of φ_f and λ_f are φ_e and λ_e, the navigator's estimate of his position.)

KM - Number of positions to be computed.

ITER - Number of iterations.

The following computations shall be performed for each value of k (k = 1, 2, 3, ---, KM):

$$\cos \varphi_k = \cos (\varphi_f + \Delta\varphi_k), \tag{G.1}$$

$$\sin \varphi_k = \sin (\varphi_f + \Delta\varphi_k), \tag{G.2}$$

$$\cos \lambda_k = \cos (\lambda_f + \Delta\lambda_k), \tag{G.3}$$

$$\sin \lambda_k = \sin (\lambda_f + \Delta\lambda_k), \tag{G.4}$$

$$D_k^2 = R_0^2 \left[\cos^2 \varphi_k + (1 - f)^2 \sin^2 \varphi_k\right], \tag{G.5}$$

$$X_{Nk} = \left[(R_0^2 / D_k) + h'\right] \cos \varphi_k \cos \lambda_k , \tag{G.6}$$

$$Y_{Nk} = \left[R_0^2 / D_k) + h'\right] \cos \varphi_k \sin \lambda_k, \tag{G.7}$$

$$Z_{Nk} = \left[\frac{R_0^2 (1 - f)^2}{D_k} + h'\right] \sin \varphi_k, \tag{G.8}$$

$$\frac{\partial X_{Nk}}{\partial \varphi} = - \left[\frac{R_0^4 (1 - f)^2}{D_k^3} + h'\right] \sin \varphi_k \cos \lambda_k , \tag{G.9}$$

$$\frac{\partial Y_{Nk}}{\partial \varphi} = - \left[\frac{R_0^4 (1 - f)^2}{D_k^3} + h'\right] \sin \varphi_k \sin \lambda_k , \tag{G.10}$$

$$\frac{\partial Z_{Nk}}{\partial \varphi} = \left[\frac{R_0^4 (1 - f)^2}{D_k^3} + h'\right] \cos \varphi_k , \tag{G.11}$$

$$\frac{\partial X_{Nk}}{\partial \lambda} = - Y_{Nk} , \text{ and} \tag{G.12}$$

$$\frac{\partial Y_{Nk}}{\partial \lambda} = X_{Nk} . \tag{G.13}$$

<u>OUTPUTS</u>: X_{Nk}, Y_{Nk}, Z_{Nk} - Navigator's coordinates at the fiducial time points (meters).

$\frac{\partial X_{Nk}}{\partial\varphi}$, $\frac{\partial Y_{Nk}}{\partial\varphi}$, $\frac{\partial Z_{Nk}}{\partial\varphi}$ - Partial derivatives of navigator's coordinates with respect to latitude at the fiducial time points (meters/radian).

$\frac{\partial X_{Nk}}{\partial\lambda}$, $\frac{\partial Y_{Nk}}{\partial\lambda}$ - Partial derivatives of navigator's coordinates with respect to longitude at the fiducial time points (meters/radian).

ITER - Number of the present iteration.

STEP H – Compute theoretical slant range differences, partial derivatives, and elevation angle.

INPUTS: X_{Nk}, Y_{Nk}, Z_{Nk} - Navigator's coordinates at the fiducial time points (meters).

$\frac{\partial X_{Nk}}{\partial\varphi}$, $\frac{\partial Y_{Nk}}{\partial\varphi}$, $\frac{\partial Z_{Nk}}{\partial\varphi}$ - Partial derivatives of navigator's coordinates with respect to latitude at the fiducial time points (meters/radian).

$\frac{\partial X_{Nk}}{\partial\lambda}$, $\frac{\partial Y_{Nk}}{\partial\lambda}$ - Partial derivatives of navigator's coordinates with respect to longitude at the fiducial time points (meter/radian).

X_{Sk}, Y_{Sk}, Z_{Sk} - Satellite coordinates at the fiducial time points (meters).

KM - Number of positions to be calculated.

The following computations shall be performed for each value of k (k = 1, 2, 3, ---, KM):

$$X_k = X_{Sk} - X_{Nk}, \tag{H.1}$$

$$Y_k = Y_{Sk} - Y_{Nk}. \tag{H.2}$$

$$Z_k = Z_{Sk} - Z_{Nk}, \tag{H.3}$$

$$S_k^2 = X_k^2 + Y_k^2 + Z_k^2, \tag{H.4}$$

$$S_k = \left[X_k^2 + Y_k^2 + Z_k^2\right]^{1/2}, \tag{H.5}$$

$$R_k^2 = X_{Sk}^2 + Y_{Sk}^2 + Z_{Sk}^2, \tag{H.6}$$

$$r_k^2 = X_{Nk}^2 + Y_{Nk}^2 + Z_{Nk}^2, \tag{H.7}$$

$$r_k = \left[X_{Nk}^2 + Y_{Nk}^2 + Z_{Nk}^2\right]^{1/2}, \tag{H.8}$$

$$\frac{\partial S_k}{\partial \varphi} = \frac{-1}{S_k}\left[X_k \frac{\partial X_{NK}}{\partial \varphi} + Y_k \frac{\partial Y_{Nk}}{\partial \varphi} + Z_k \frac{\partial Z_{Nk}}{\partial \varphi}\right] \tag{H.9}$$

$$\frac{\partial S_k}{\partial \lambda} = \frac{-1}{S_k}\left[X_k \frac{\partial X_{Nk}}{\partial \lambda} + Y_k \frac{\partial Y_{Nk}}{\partial \lambda}\right] \tag{H.10}$$

$$\sin E_k = \left[\frac{X_k X_{Nk} + Y_k Y_{Nk} + Z_k Z_{Nk}}{S_k r_k}\right], \text{ and} \tag{H.11}$$

$$\text{If } \sin E_{k+1} < \sin E_k \text{ then } \sin E_{max} = \sin E_k . \qquad \text{(H. 12)}$$

OUTPUTS: S_k - Table of theoretical slant ranges at the fiducial time points (meters).

$\frac{\partial S_k}{\partial \varphi}, \frac{\partial S_k}{\partial \varphi}$ - Table of partial derivatives of the theoretical slant ranges with respect to latitude and longitude at the fiducial time points (meters/radian).

$\sin E_{max}$ - Sine of maximum elevation angle for the pass (dimensionless).

STEP I – Compute refraction corrected measured slant range differences.

INPUTS: N_k - Table of refraction corrected "vacuum" doppler counts (cycles).

K - Number of cycle counts.

L_o - Wavelength of navigator's estimate of offset frequency (meters).

$\overline{f}_o$ - Initial value of offset frequency 1 920 000 cycles/min [32 000 cycles/sec]

The following equation shall be performed for each value of k (k = 1, 2, 3, ---, KM-1):

$$S_{ko} = N_k L_o - 2.0 \overline{f}_o L_o \qquad \text{(I. 1)}$$

OUTPUT: $\hat{S}_{ko}$ - Table of measured slant range differences (meters) for KM points.

Note: If any value of $N_k = 0$ the corresponding value of

$$\hat{S}_{ko} = 0.$$

STEP J – Form the C matrix.

INPUTS: $\hat{S}_{ko}$ - Table of (KM-1) measured slant range differences (meters).

S_k - Table of (KM) theoretical slant ranges at the fiducial time points (meters).

$\frac{\partial S_k}{\partial \varphi}, \frac{\partial S_k}{\partial \lambda}$ - Table of (KM) partial derivatives of the theoretical slant ranges with respect to latitude and longitude at the fiducial time points (meters/radian).

The following equations shall be done for each value of k (k = 1, 2, 3, ---, KM-1), for which

$$\hat{S}_{ko} \neq 0:$$

$$C_{J0} = - \hat{S}_{ko} + \left[S_{k+1} - S_k \right], \tag{J. 1}$$

$$C_{J1} = - 2.0 \; L_0 , \tag{J. 2}$$

$$C_{J2} = - \frac{\partial S_{k+1}}{\partial \varphi} + \frac{\partial S_k}{\partial \varphi}, \text{ and} \tag{J. 3}$$

$$C_{J3} = -\frac{\partial S_{k+1}}{\partial \lambda} + \frac{\partial S_k}{\partial \lambda} . \tag{J.4}$$

OUTPUT: The C matrix

$$\begin{bmatrix} C_{10} & C_{11} & C_{12} & C_{13} \\ C_{20} & C_{21} & C_{22} & C_{23} \\ \cdot & \cdot & \cdot & \cdot \\ \cdot & \cdot & \cdot & \cdot \\ \cdot & \cdot & \cdot & \cdot \\ C_{J0} & C_{J1} & C_{J2} & C_{J3} \end{bmatrix}$$

J - Number of rows in the C matrix.

STEP K – Form the A matrix.

INPUTS: - C matrix elements.

J - Number of rows in C matrix.

$$a_{10} = \sum_{m=1}^{J} C_{m1} C_{m0} , \tag{K.1}$$

$$a_{20} = \sum_{m=1}^{J} C_{m2} C_{m0} , \tag{K.2}$$

$$a_{30} = \sum_{m=1}^{J} C_{m3} C_{m0} , \tag{K.3}$$

$$a_{11} = \sum_{m=1}^{J} C_{m1} C_{m1} , \tag{K.4}$$

$$a_{21} = \sum_{m=1}^{J} C_{m2} \; C_{m1} \,, \qquad \text{Note: } a_{21} = a_{12},\; a_{31} = a_{13},\; a_{32} = a_{23} \tag{K. 5}$$

$$a_{31} = \sum_{m=1}^{J} C_{m3} \; C_{m1} \,, \tag{K. 6}$$

$$a_{12} = a_{21}, \tag{K. 7}$$

$$a_{22} = \sum_{m=1}^{J} C_{m2} \; C_{m2}, \tag{K. 8}$$

$$a_{32} = \sum_{m=1}^{J} C_{m3} \; C_{m2}, \tag{K. 9}$$

$$a_{13} = a_{31}, \tag{K. 10}$$

$$a_{23} = a_{32}, \text{ and} \tag{K. 11}$$

$$a_{33} = \sum_{m=1}^{J} C_{m3} \; C_{m3} \,. \tag{K. 12}$$

<u>OUTPUT</u>: A matrix

where

$$-a_{10} + a_{11} \, \Delta f + a_{12} \, \Delta \varphi + a_{13} \, \Delta \lambda = 0,$$

$$-a_{20} + a_{21} \, \Delta f + a_{22} \, \Delta \varphi + a_{23} \, \Delta \lambda = 0, \text{ and}$$

$$-a_{30} + a_{31} \, \Delta f + a_{32} \, \Delta \varphi + a_{23} \, \Delta \lambda = 0.$$

STEP L – Solve for Δf, $\Delta\varphi$, $\Delta\lambda$ and update estimates of f, φ, and λ.

INPUT: A matrix elements.

$$B11 = a_{22} - a_{12}\frac{a_{12}}{a_{11}}, \tag{L. 1}$$

$$B12 = a_{23} - a_{13}\frac{a_{12}}{a_{11}}, \tag{L. 2}$$

$$B10 = a_{20} - a_{10}\frac{a_{12}}{a_{11}}, \quad \text{Note: } a_{12} = a_{21},\ a_{13} = a_{31},\ a_{32} = a_{23} \tag{L. 3}$$

$$B22 = a_{33} - a_{13}\frac{a_{13}}{a_{11}}, \tag{L. 4}$$

$$B20 = a_{30} - a_{10}\frac{a_{13}}{a_{11}}, \tag{L. 5}$$

$$\Delta = B11\ B22 - B12\ B12, \tag{L. 6}$$

$$\Delta\varphi = (B22\ B10 - B12\ B20)/\Delta, \tag{L. 7}$$

$$\Delta\lambda = (B11\ B20 - B12\ B10)/\Delta, \tag{L. 8}$$

$$\Delta f = \frac{a_{10} - (a_{12})(\Delta\varphi) - (a_{13})(\Delta\lambda)}{a_{11}}, \tag{L. 9}$$

$$f = f + \Delta f \text{ where } f = \bar{f}_0 \text{ on first iteration,} \tag{L. 10}$$

$$\varphi_f = \varphi_f + \Delta\varphi, \text{ and} \tag{L. 11}$$

$$\lambda_f = \lambda_f + \Delta\lambda. \tag{L. 12}$$

OUTPUTS: Δf - Incremental change in navigator's estimate of offset frequency (cycles/min).

$\Delta\varphi$ - Incremental change in navigator's estimated latitude (radians).

$\Delta\lambda$ - Incremental change in navigator's estimated longitude (radians).

f - Estimated offset frequency (cycles/min). this iteration.

φ_f - Estimated latitude (radians) this iteration.

λ_f - Estimated longitude (radians) this iteration.

STEP M — Write out results.

INPUTS: ITER - Number of this iteration.

φ_e, λ_e - Navigator's initial position estimate (radians).

φ_f, λ_f - Navigator's calculated position this iteration (radians).

$\bar{f}_o$ - Initial value of offset frequency (1 920 000 cycles/min).

f - Navigator's estimate of frequency offset this iteration (cycles/min).

T_0 - First fiducial time (minutes).

IDAY - Day number of pass.

$\sin E_{max}$ - Sine of maximum elevation angle for the pass.

NDOP - Number of doppler counts used in calculation this iteration.

Residual - Residual difference between measured and theoretical slant range differences (meters).

$$DL = \varphi_f - \varphi_e , \tag{M.1}$$

$$DLO = \lambda_f - \lambda_e , \tag{M.2}$$

$$FRQ = f - \bar{f}_o , \text{ and} \tag{M.3}$$

$$TIME = T_0 + 4 . \tag{M.4}$$

<u>OUTPUTS:</u>

ITER - Number of this iteration.

DLA, DLO - Total change in navigator's position (radians).

FRQ - Total change in frequency (cycles/min).

φ_f, λ_f - Navigator's calculated position this iteration (radians).

TIME - Fix time (minutes).

IDAY - Day number of pass.

$\sin E_{max}$ - Sine of maximum elevation for pass.

NDOP - Number of doppler counts used in calculations.

Residual - Residual of difference between measured and theoretical slant range differences.

OUTPUTS (Continued)

$$\text{RMS} = \sqrt{\Sigma \frac{\text{Residual}^2}{\text{NDOP-1}}}$$

STEP N – Test for convergence.

INPUTS: Δf - Incremental change in navigator's estimate of offset frequency (cycles/min).

$\Delta\varphi$ - Incremental change in navigator's latitude (radians).

$\Delta\lambda$ - Incremental change in navigator's estimated longitude (radians).

ITER - Number of the present iteration.

If $\Delta f >$ 2.4 cycle/min, (N.1)

or if $\Delta\varphi > 1.2 \times 10^{-7}$ radian,*

or if $\Delta\lambda > \dfrac{1.2 \times 10^{-7}}{\cos \varphi_f}$*,

and if ITER < 10 then return to Step G. Otherwise go to Step O to edit doppler data or Step P to compute alerts.

STEP O – Edit doppler data.

INPUTS: N_k - Table of (KM-1) refraction corrected "vacuum" doppler counts for each 2-minute interval (cycles).

NDOP - Total number of nonzero values in N_k table.

*This convergence criterion is equivalent to 0.0004 nmi. Without loss of significant accuracy this criterion can be broadened to 0.001 nmi or (in radians) approximately 3×10^{-7}.

KM - Number of fiducial times, etc.

If NDOP > 4, repeat Steps G and H for each value of k (k = 1, 2, 3, ---, KM).

If $\sin E_{KM-k+1} \leq \sin 7.5°$ and (O. 1)

$\sin E_{KM-k+1} \leq \sin E_k$ and

$N_{KM-k} > 0$ then

$N_{KM-k} = 0$ and

NDOP = NDOP - 1.

Or if $\sin E_{KM-k+1} > \sin 7.5°$ and (O. 2)

$\sin E_k \leq \sin 7.5°$ and

$N_{k+1} > 0$ then

$N_{k+1} = 0$ and

NDOP = NDOP - 1.

Otherwise make no changes in the N_k table.

OUTPUTS: Edited N_k table and updated value of NDOP. Repeat Steps G - N.

STEP P – Compute alerts.

INPUTS: T_0 - Time of first fiducial point of last pass (minutes).

IDAY - Day number of last pass.

MDAY - Day number of last day for which alerts are to be calculated.

- Satellite data from last pass and navigator's estimated coordinates during the period IDAY to MDAY.

KM - Number of positions to be calculated.

ISTP = MDAY-IDAY. If ISTP < 0, let ISTP = ISTP + 365. (P. 1)

Let $T_0 = T_0 - 18$, KM = 1, DE(K) = 0, DA(K) = 0, DN(K) = 0, I = 1, 2, 3, ---, ISTP, KDAY = I + IDAY. (P. 2)

Execute Steps F, G, and H. (P. 3)

If $E_k \leq 0$ let $T_0 = T_0 + 10$, and repeat Step P. 3 increasing T_0 by 10 each repetition until $E_k > 0$. (P. 4)

When $E_k > 0$ let $T_0 = T_0 - 10$, repeat Step P. 3, and then execute Step P. 6. (P. 5)

If $E_k \leq 0$, let $T_0 = T_0 + 2$, repeat Step P. 3 increasing T_0 by 2 each time until $E_k \geq 0$, and then execute Step P. 7. (P. 6)

When $E_k \geq 0$ let $T_0 - 2$ = RISE, $E_k = E_A$, $T_0 = T_0 + 0.25$ and repeat Step P. 3 increasing T_0 by 0.25 and letting the new value of $E_k = E_A$ each time until $E_k < E_A$. Then E_A = maximum elevation for that pass. (P. 7)

Write out day number of alert day, RISE time (hours and minutes), and maximum elevation angle for the alert pass. (P. 8)

Let $T_0 = T_0 + 10$ then repeat Steps P. 3 through P. 8 incrementing I and K until I > ISTP indicating that all alerts through the end of MDAY have been obtained. (P. 9)

<u>OUTPUTS:</u>	KDAY	-	Day number of alert day.
	RISE	-	Time of rise (hours and minutes) of alert pass.
	E_A	-	Maximum pass elevation (degrees).

8. FORTRAN PROGRAM FOR THREE-VARIABLE NAVIGATION SOLUTION AND ALERT CALCULATIONS

The steps given in Section 7 for the three-variable navigation solutions and for the alert computations have been programmed in FORTRAN. A listing of the program routines is at the end of this Section. Table 7 shows the interface requirements between the real-time data processing program and the navigation fix program and also gives the FORTRAN names of the required parameters, all of which have been discussed in previous sections. The subroutines of the navigation fix program perform the operations described in the next section. Flow charts for the program are in Appendix A.

SUBROUTINES

MAIN

This subroutine is the master routine serving as a driver for the other program routines.

INPUT

Subroutine INPUT allows the program to be used in nonreal-time navigation for study, diagnostic, or debug purposes. It is not used in real-time navigation.

CVTM

Subroutine CVTM (Fig. A-19) scales the constant orbit parameters from their input format to the format used in the program, corrects the doppler data for ionospheric refraction, formats navigator motion for further computation, computes the time of the first fiducial mark, decodes the out-of-plane (cross plane) orbit correction words, and interpolates for the missing out-of-plane corrections (Steps A - D of Section 7).

Table 7

Interface Requirements Between Real-Time Data Processing Program and Navigation Fix Program

Program Parameter Name	Description	Input Format	Input Units	Computational Units	Comments	No of Par	Source
ELAT	Estimated Latitude	FP	Min $*10^4$	Radians		1	Navigator
ELON	Estimated Longitude	FP	Min $*10^4$	Radians		1	Navigator
GEOH	Antenna Height	FP	Meters	Meters		1	Navigator
ETIM	Estimated Lock Time	FP	Minutes	Minutes		1	Navigator
HEAD	Ship's Heading	FP	Minutes	Radians		1	Navigator
RATE	Ship's Speed	FP	Knots $*10$	Radians/Min $*2$		1	Navigator
IDAY	Day of Pass	Integers	Days	Days	15 bit dressed Rt	1	Navigator
MDAY	Alert End Day	Integers	Days	Days	15 bit dressed Rt	1	Navigator
DOP(K)	400-MHz Doppler	FP	Cycles	Cycles	=0 Invalid	8	Satellite Signal
REF(K)	Refraction Correction	FP	Cycles	Cycles	=0 Invalid	8	Satellite Signal
DE(K)	Eccentric Anomaly Correction	FP	Degrees $*10^4$	Radians		9	Satellite Message
DA(K)	Semimajor Axis Correction	FP	Meters/10	Meters		9	Satellite Message
DN(K)	Cross Plane Term (transmitted as values at 4-min intervals and interpolated to yield values at 2-min intervals)	FP	$\frac{\text{Meters}}{10 \text{ or } 100}$	Meters	XS3 MSD Alternate LSD	11	Satellite Message
DTK	Lock Time Since Half Hour	FP	Minutes/2	Minutes		1	Satellite Message
TP	Time of Perigee	FP	Min/$*10^5$	Minutes		1	Satellite Message
XNDT	Mean Motion	FP	Deg/Min $*10^{8}-3$	Rad/Min		1	Satellite Message
SOME	Argument of Perigee	FP	Degrees $*10^5$	Radians		1	Satellite Message
SOMD	Precession Rate of Perigee	FP	Deg/Min $*10^8$	Rad/Min		1	Satellite Message
E	Eccentricity	FP	Deg/Min $*10^7$	Dimensionless		1	Satellite Message
AO	Mean Semimajor Axis	FP	Meters	Meters		1	Satellite Message
COME	Right Ascension of Ascending Node	FP	Degrees $*10^5$	Radians		1	Satellite Message
COMD	Precession Rate of Node	FP	Deg/Min $*10^8$	Rad/Min		1	Satellite Message
CI	Cosine Inclination	FP	Deg/Min $*10^7$	Dimensionless		1	Satellite Message
XLMG	Greenwich Long. at TP	FP	Degrees $*10^5$	Radians		1	Satellite Message
SI	Sine Inclination	FP	Degrees $*10^7$	Dimensionless		1	Satellite Message
DLAT(K)	Relative Lat. Motion			Radians	Calculated from Head	9	Navigator
DLON(K)	Relative Long. Motion			Radians		9	Navigator
STIM	Correct Msg. Lock Time			Minutes		1	Satellite Message

SATC AND SXYZ

Subroutine SATC (Fig. A-20) computes the time since perigee (Step E of Section 7) and then calls subroutine SXYZ to compute the satellite coordinates for one 2-minute point. Return is made to subroutine SATC to increment time, and subroutine SXYZ is called again to compute the satellite coordinates for the next 2-minute point. The net effect of this sequence is the execution of Step F of Section 7.

SOLVE AND SLANT

The programming approach adopted in subroutines SOLVE and SLANT (Figs. A-21 and A-22) is to set up the elements of the final A matrix and then incrementally modify each element with its C matrix counterpart by means of an iterative process. The net effect of the sequence is the execution of Steps G - L and the determination of the sum of the squares of the residual differences between the measured and theoretical slant ranges, as follows:

Subroutine SOLVE begins by setting up the elements of the A matrix.* Subroutine SLANT is called and the navigator's coordinates and partial derivatives are calculated for the first time point (Step G). Next, the theoretical slant range for the first time point is calculated, plus the partial derivatives and the elevation angle to the satellite (Step H). Return is then made to subroutine SOLVE to compute the constant function of satellite frequency vacuum wavelength. The interval count is incremented and subroutine SLANT is called again to compute the next theoretical slant range, partial derivatives, and elevation

---

*Inasmuch as Fortran arrays may not be indexed with a subzero term, the term for the residual, which is expressed as C_0 in Section 7, is changed to C(4) in the Fortran listing of Section 8.

angle. Return is made to subroutine SOLVE and the differences in successive theoretical slant ranges and partial derivatives of the slant ranges are calculated. Next, if the doppler count is positive, the refraction corrected measured slant range differences are calculated (Step I). The residual difference between the measured and theoretical slant ranges is determined. The C matrix is formed (Step J), the A matrix is formed (Step K), the matrix is solved for the differences in frequency, offset, latitude, and longitude (Step L), and the navigator's estimates of frequency offset and fix position are updated. The convergence test is made (Step N). If no convergence is found, return is made to Step G and the iterative loop repeated until convergence is achieved or until 10 iterations have been made. (If convergence is not achieved after 10 iterations, further attempts at solution are abandoned, and the program terminates). If convergence is achieved, subroutine EDIT is called.

EDIT

Subroutine EDIT (Fig. A-22) examines the doppler data and eliminates data points for elevation angles of 7.5° or below until at least four doppler points remain (Step O). Subroutines SOLVE and SLANT are then repeated using the edited doppler data.

TYPE, UCON, and ARCS

Subroutine TYPE (Fig. A-23) is called to write out the results (Step M). The difference in the fix frequency and the estimated frequency is calculated. The maximum pass elevation is calculated and is converted to degrees in subroutine ARCS (Fig. A-24). Fix time is calculated as the time of the first fiducial point plus 4 minutes and is converted to hours and minutes in subroutine UCON (Fig. A-24). The number of iterations and the number of doppler counts used in the solution are listed. The differences in the estimated and fix latitude and longitude are calculated.

ALERT and AVIS*

If the navigator has elected to calculate alerts, subroutine ALERT (Fig. A-25) is used. Subroutine ALERT, which calls subroutine AVIS (Fig. A-25), calculates the times of future satellite passes by computing the elevation angle at future times. A positive elevation angle is construed as an indication that a pass will be underway at that time (Step P).

PROGRAM LISTING

A listing of the program follows.

*Subroutines ALERT and AVIS are not used with the Fortran program listed on the following pages and cannot be called in this program; they are included for illustration.

```
       COMPILER OPTIONS - NAME=  MAIN,OPT=02,LINECNT=58,SIZE=0000K,
                          SOURCE,EBCDIC,NOLIST,NODECK,LOAD,MAP,NOEDIT,ID,NOXREF
              C------------ - ------------EXEC DEBUG --------------------------------EXEC
              C                                                                     EXEC
              C                                                                     EXEC
ISN 0002           1 FORMAT (1H ,(3F15.1//))                                        EXEC
              C                                                                     EXEC
ISN 0003            DOUBLE PRECISION TAW,WAVE,CVCG,EFRQ,OMGE,XOSQ,ZOSQ              EXEC
ISN 0004            DOUBLE PRECISION ONE,TWO,THRE,FIVE,ATE,TEN,D60,HUND,C480,S7P5   EXEC
ISN 0005            DOUBLE PRECISION TOPI,DTRA,DTOM,TM1,TM4,TM5,TM8,CMTR,CKRM       EXEC
ISN 0006            DOUBLE PRECISION ZERO,FOUR,TM7,C2K,C2M,REFC                     EXEC
ISN 0007            DOUBLE PRECISION DOP,REF,DE,DA,DN,ELAT,ELON,GEOM,ETIM,HEAD,RATE EXEC
ISN 0008            DOUBLE PRECISION DTA,TP,XNOT,SOME,SOMD,E,AO,COME,COMD,CI,XLMG   EXEC
ISN 0009            DOUBLE PRECISION DUM1,DUM2,SI,OFST,DUM3,DUM4,DUM5               EXEC
ISN 0010            DOUBLE PRECISION DLAT,DLON,SMXE,SELV,FLAT,FLON,FFRQ,RSQ,VN      EXEC
ISN 0011            DOUBLE PRECISION T,TEMP,A,DUM                                   EXEC
              C                                                                     EXEC
              C-DIMENSION                                                           EXEC
ISN 0012            DIMENSION DOP(8),REF(8),DE(9),DA(9),DN(11),DLAT(9),DLON(9)      EXEC
ISN 0013            DIMENSION A(_,4),DUM(10)                                        EXEC
              C                                                                     EXEC
              C-COMMON                                                              EXEC
ISN 0014            COMMON TP,XNOT,SOME,SOMD,E,AO,COME,COMD,CI,XLMG                 EXEC
ISN 0015            COMMON DUM1,DUM2,SI,OFST,DUM3,DUM4,DUM5,DOP                     EXEC
ISN 0016            COMMON REF                                                      EXEC
ISN 0017            COMMON DE,DA,DN,DTA,ELAT,ELON,GEOM,HEAD,RATE,IDAY,MDAY,ETIM     EXEC
ISN 0018            COMMON DLAT,DLON,SMXE,SELV,FLAT,FLON,FFRQ,RSQ,VN                EXEC
ISN 0019            COMMON I,J,K,L,M,N,NDCP,ITER                                    EXEC
ISN 0020            COMMON T,TEMP,A,DUM                                             EXEC
              C                                                                     EXEC
ISN 0021            COMMON /COMC/NULL,IONE,ITWO,IFOR,I15,I30,I365,IM,KM,KF          EXEC
ISN 0022            COMMON /COMC/TAW,WAVE,CVCG,EFRQ,OMGE,XOSQ,ZOSQ,ZERO             EXEC
ISN 0023            COMMON /COMC/ONE,TWO,THRE,FOUR,FIVE,ATE,TEN,D60,HUND            EXEC
ISN 0024            COMMON /COMC/C480,S7P5,TOPI,DTRA,DTOM                           EXEC
ISN 0025            COMMON /COMC/TM1,TM4,TM5,TM7,TM8,CMTR,CKRM,C2K,C2M,REFC         EXEC
              C                                                                     EXEC
              C---------------------------CONSTANTS---------------------------------EXEC
              C---SYSTEM CONSTANTS                                                  EXEC
              C     TAW=2.D+0                                                       EXEC
              C     WAVE=7.4948125D-1                                               EXEC
              C          METERS VACUUM WAVE LENGTH                                  EXEC
              C     CVCG=1.2D-7                                                     EXEC
              C          RADIANS CONVERGENCE CRITERIA = .0004 NM                    EXEC
              C     FFRQ=1.92D+6                                                    EXEC
              C     KM=9                                                            EXEC
              C     IM=8                                                            EXEC
              C     KF=3                                                            EXEC
              C---EARTH CONSTANTS                                                   EXEC
              C     OMGE=4.37526951D-3                                              EXEC
              C          RAD/MIN EARTHS ROTATION RATE                               EXEC
              C     XO =6.378144D+6                                                 EXEC
              C          METERS SEMI MAJOR AXIS                                     EXEC
              C     EFLT= 2.9823D+2                                                 EXEC
              C          FLATTENING COEFFICIENT                                     EXEC
              C     XOSQ=XO*XO                                                      EXEC
              C     ONE=1.D+0                                                       EXEC
              C     ZO=XO*(ONE-ONE/EFLT)                                            EXEC
```



```
              C     ZOSQ=ZO*ZO                                                      EXEC
              C---UNIT CONVERSIONS AND MISCELLANEOUS                                EXEC
              C     NULL=0                                                          EXEC
              C     IONE=1                                                          EXEC
              C     ITWO=2                                                          EXEC
              C     IFOR=4                                                          EXEC
              C                                                                     EXEC
ISN 0026            REWIND 8                                                        EXEC
ISN 0027          2 CALL INPUT                                                      EXEC
ISN 0028            CALL CVTM                                                       EXEC
ISN 0029            CALL SATC                                                       EXEC
ISN 0030            CALL SOLVE                                                      EXEC
ISN 0031            IFIX=ITER                                                       EXEC
ISN 0032            CALL EDIT                                                       EXEC
ISN 0033            CALL SOLVE                                                      EXEC
ISN 0034            ITER=IFIX                                                       EXEC
ISN 0035            CALL TYPE                                                       EXEC
ISN 0036            GO TO 2                                                         EXEC
ISN 0037            END                                                             EXEC
```

/ MAIN / SIZE OF PROGRAM 000140 HEXADECIMAL BYTES PAGE 003

NAME	TAG	TYPE	ADD.	NAME	TAG	TYPE	ADD.	NAME	TAG	TYPE	ADD.	NAME	TAG	TYPE	ADD.
A	C	R*8	N.R.	E	C	R*8	N.R.	I	C	I*4	N.R.	J	C	I*4	N.R.
K	C	I*4	N.R.	L	C	I*4	N.R.	M	C	I*4	N.R.	N	C	I*4	N.R.
T	C	R*8	N.R.	AD	C	R*8	N.R.	CI	C	R*8	N.R.	DA	C	R*8	N.R.
DE	C	R*8	N.R.	DN	C	R*8	N.R.	IM	C	I*4	N.R.	KF	C	I*4	N.R.
KM	C	I*4	N.R.	SI	C	R*8	N.R.	IP	C	R*8	N.R.	VN	C	R*8	N.R.
ATE	C	R*8	N.R.	C2K	C	R*8	N.R.	C2M	C	R*8	N.R.	DOP	C	R*8	N.R.
DTK	C	R*8	N.R.	DUM	C	R*8	N.R.	D60	C	R*8	N.R.	I15	C	I*4	N.R.
I30	C	I*4	N.R.	ONE	C	R*8	N.R.	REF	C	R*8	N.R.	RSQ	C	R*8	N.R.
TAW	C	R*8	N.R.	TEN	C	R*8	N.R.	TM1	C	R*8	N.R.	TM4	C	R*8	N.R.
TM5	C	R*8	N.R.	TM7	C	R*8	N.R.	TM8	C	R*8	N.R.	TWO	C	R*8	N.R.
CKRM	C	R*8	N.R.	CNTR	C	R*8	N.R.	COND	C	R*8	N.R.	COME	C	R*8	N.R.
CVCG	C	R*8	N.R.	CVTM SF	XF	R*4	000000	C480	C	R*8	N.R.	DLAT	C	R*8	N.R.
DLON	C	R*8	N.R.	DTOM	C	R*8	N.R.	DTRA	C	R*8	N.R.	DUM1	C	R*8	N.R.
DUM2	C	R*8	N.R.	DUM3	C	R*8	N.R.	DUM4	C	R*8	N.R.	DUM5	C	R*8	N.R.
EDIT SF	XF	R*4	000000	EFRQ	C	R*8	N.R.	ELAT	C	R*8	N.R.	ELON	C	R*8	N.R.
ETIM	C	R*8	N.R.	FFRQ	C	R*8	N.R.	FIVE	C	R*8	N.R.	FLAT	C	R*8	N.R.
FLON	C	R*8	N.R.	FOUR	C	R*8	N.R.	GEOM	C	R*8	N.R.	HEAD	C	R*8	N.R.
HUND	C	R*8	N.R.	IDAY	C	I*4	N.R.	IFIX SF		I*4	00008C	IFOR	C	I*4	N.R.
IONE	C	I*4	N.R.	ITER SF	C	I*4	000314	ITMD	C	I*4	N.R.	I365	C	I*4	N.R.
MDAY	C	I*4	N.R.	NOOP	C	I*4	N.R.	NULL	C	I*4	N.R.	OFST	C	R*8	N.R.
OMGE	C	R*8	N.R.	RATE	C	R*8	N.R.	REFC	C	R*8	N.R.	SATC SF	XF	R*4	000000
SELV	C	R*8	N.R.	SMXE	C	R*8	N.R.	SOND	C	R*8	N.R.	SOME	C	R*8	N.R.
STPS	C	R*8	N.R.	TEMP	C	R*8	N.R.	THRE	C	R*8	N.R.	TOPI	C	R*8	N.R.
TYPE SF	XF	R*4	000000	WAVE	C	R*8	N.R.	XLNG	C	R*8	N.R.	XNDT	C	R*8	N.R.
XOSQ	C	R*8	N.R.	ZERO	C	R*8	N.R.	ZOSQ	C	R*8	N.R.	INPUT SF	XF	I*4	000000
SOLVE SF	XF	R*4	000000	IBCOM# F	XF	R*4	000000								

***** COMMON INFORMATION *****

NAME OF COMMON BLOCK * * SIZE OF BLOCK 00030[illegible] HEXADECIMAL BYTES

VAR. NAME	TYPE	REL. ADDR.	VAR. NAME	TYPE	REL. ADDR.	VAR. NAME	TYPE	REL. ADDR.	VAR. NAME	TYPE	REL. ADDR.
IP	R*8	N.R.	XNDT	R*8	N.R.	SOME	R*8	N.R.	SOMD	R*8	N.R.
E	R*8	N.R.	AD	R*8	N.R.	COME	R*8	N.R.	COND	R*8	N.R.
CI	R*8	N.R.	XLNG	R*8	N.R.	DUM1	R*8	N.R.	DUM2	R*8	N.R.
SI	R*8	N.R.	OFST	R*8	N.R.	DUM3	R*8	N.R.	DUM4	R*8	N.R.
DUM5	R*8	N.R.	DOP	R*8	N.R.	REF	R*8	N.R.	DE	R*8	N.R.
DA	R*8	N.R.	DN	R*8	N.R.	DTK	R*8	N.R.	ELAT	R*8	N.R.
FLON	R*8	N.R.	GEOM	R*8	N.R.	HEAD	R*8	N.R.	RATE	R*8	N.R.
IDAY	I*4	N.R.	MDAY	I*4	N.R.	ETIM	R*8	N.R.	DLAT	R*8	N.R.
ELON	R*8	N.R.	SMXE	R*8	N.R.	SELV	R*8	N.R.	FLAT	R*8	N.R.
FLON	R*8	N.R.	FFRQ	R*8	N.R.	RSQ	R*8	N.R.	VN	R*8	N.R.
I	I*4	N.R.	J	I*4	N.R.	K	I*4	N.R.	L	I*4	N.R.
M	I*4	N.R.	N	I*4	N.R.	NOOP	I*4	N.R.	ITER	I*4	000314
T	R*8	N.R.	TEMP	R*8	N.R.	A	R*8	N.R.	DUM	R*8	N.R.

NAME OF COMMON BLOCK * COM2* SIZE OF BLOCK 000126 HEXADECIMAL BYTES

VAR. NAME	TYPE	REL. ADDR.	VAR. NAME	TYPE	REL. ADDR.	VAR. NAME	TYPE	REL. ADDR.	VAR. NAME	TYPE	REL. ADDR.
NULL	I*4	N.R.	IONE	I*4	N.R.	ITMD	I*4	N.R.	IFOR	I*4	N.R.
I15	I*4	N.R.	I30	I*4	N.R.	I365	I*4	N.R.	IM	I*4	N.R.
KM	I*4	N.R.	KF	I*4	N.R.	TAW	R*8	N.R.	WAVE	R*8	N.R.

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CVCG	R*8	N.R.	EFRQ	R*8	N.R.	OMGE	R*8	N.R.	XOSQ	R*8	N.R.
ZOSQ	R*8	N.R.	ZERO	R*8	N.R.	ONE	R*8	N.R.	TWO	R*8	N.R.
THRE	R*8	N.R.	FOUR	R*8	N.R.	FIVE	R*8	N.R.	ATE	R*8	N.R.
TEN	R*8	N.R.	D60	R*8	N.R.	HUND	R*8	N.R.	C480	R*8	N.R.
STPS	R*8	N.R.	TOPI	R*8	N.R.	DTRA	R*8	N.R.	DTOM	R*8	N.R.
TM1	R*8	N.R.	TM4	R*8	N.R.	TM5	R*8	N.R.	TM7	R*8	N.R.
TM8	R*8	N.R.	CNTR	R*8	N.R.	CKRM	R*8	N.R.	C2K	R*8	N.R.
C2M	R*8	N.R.	REFC	R*8	N.R.						

```
  LABEL   ADDR              LABEL   ADDR              LABEL   ADDR              LABEL   ADDR           PAGE 005
     2  0000C8
*OPTIONS IN EFFECT*     NAME=  MAIN,OPT=02,LINECNT=58,SIZE=0000K,
*OPTIONS IN EFFECT*     SOURCE,EBCDIC,NOLIST,NODECK,LOAD,MAP,NOEDIT,ID,NOXREF
*STATISTICS*     SOURCE STATEMENTS =      36 ,PROGRAM SIZE =      320
*STATISTICS*  NO  DIAGNOSTICS GENERATED
****** END OF COMPILATION ******                                        61K BYTES OF CORE NOT USED
```

```
        COMPILER OPTIONS - NAME=  MAIN,OPT=02,LINECNT=58,SIZE=0000K,
                           SOURCE,EBCDIC,NOLIST,NODECK,LOAD,MAP,NOEDIT,ID,NOXREF
 ISN 0002          BLOCK DATA                                                        BKDATA
 ISN 0003          DOUBLE PRECISION TAW,WAVE,CVCG,EFRQ,OMGE,XOSQ,ZOSQ                BKDATA
 ISN 0004          DOUBLE PRECISION ONE,TWO,THRE,FIVE,ATE,TEN,D60,HUND C480,STPS     BKDATA
 ISN 0005          DOUBLE PRECISION TOPI,DTRA,DTOM,TM1,TM4,TM5,TM8,CMTR,CKRM         BKDATA
 ISN 0006          DOUBLE PRECISION ZERO,FOUR,TM7,C2K,C2M,REFC                       BKDATA
             C                                                                       BKDATA
             C---COMMON                                                              BKDATA
 ISN 0007          COMMON /COMC/NULL,IONE,ITWO,IFOR,I15,I30,I365,IM,KM,KF            BKDATA
 ISN 0008          COMMON /COMC/TAW,WAVE,CVCG,EFRQ,OMGE,XOSQ,ZOSQ,ZERO               BKDATA
 ISN 0009          COMMON /COMC/ONE,TWO,THRE,FOUR,FIVE,ATE,TEN,D60,HUND              BKDATA
 ISN 0010          COMMON /COMC/C480,STPS,TOPI,DTRA,DTOM                             BKDATA
 ISN 0011          COMMON /COMC/TM1,TM4,TM5,TM7,TM8,CMTR,CKRM,C2K,C2M,REFC           BKDATA
             C                                                                       BKDATA
 ISN 0012          DATA NULL  ,IONE  ,ITWO  ,IFOR  ,I15   ,I30   ,I365               BKDATA
                  1    /    0,     1,     2,     4,    15,    30,     365 /          BKDATA
 ISN 0013          DATA IM  ,KM  ,KF                                                 BKDATA
                  1    / 8,   9,   3 /                                               BKDATA
 ISN 0014          DATA TAW    ,WAVE              ,CVCG                              BKDATA
                  1    /  200,     7.4948125D-1,    1.2D-7 /                         BKDATA
 ISN 0015          DATA EFRQ          ,OMGE                                          BKDATA
                  1    /    1.92D+6,      4.37526951D-3  /                           BKDATA
 ISN 0016          DATA XOSQ                      ,ZOSQ                              BKDATA
                  1    /    .40680720884736D+14,        .40408363863095D+14  /       BKDATA
 ISN 0017          DATA ZERO    ,ONE     ,TWO     ,THRE     ,FOUR                    BKDATA
                  1    /    0D0,     1D0,     2D0,      3D0,      4D0 /              BKDATA
 ISN 0018          DATA FIVE    ,ATE     ,TEN         ,D60                           BKDATA
                  1    /    5D0,     8D0,     1.0D+1,     6.0D+1  /                  BKDATA
 ISN 0019          DATA HUND    ,C480        ,STPS                                   BKDATA
                  1    /    1D+2,      4.8D+2,       .13053D0    /                   BKDATA
 ISN 0020          DATA TOPI                    ,DTRA                                BKDATA
                  1    /    6.2831853072D0,       1.7453292519943D-2     /           BKDATA
 ISN 0021          DATA DTOM          ,TM1       ,TM4       ,TM5                     BKDATA
                  1    /    1.44D+3,     1D-1,      1D-4,      1D-5  /               BKDATA
 ISN 0022          DATA TM7      ,TM8       ,CMTR                                    BKDATA
                  1    /  1D-7,     1D-8,       2.90888208D-4                        BKDATA
 ISN 0023          DATA CKRM               ,C2K       ,C2M                           BKDATA
                  1    /    9.678d536D-7,     2.D+3,     2.D+5   /                   BKDATA
 ISN 0024          DATA REFC/.43636300 /                                             BKDATA
             C--NOTE CONSTANTS                                                       BKDATA
             C     I15=15                                                            BKDATA
             C     I30=30                                                            BKDATA
             C     I365=365                                                          BKDATA
             C     ZERO=0.D+0                                                        BKDATA
             C     TWO=2.D+0                                                         BKDATA
             C     THRE=3.D+0                                                        BKDATA
             C     FOUR=4.D+0                                                        BKDATA
             C     FIVE=5.D+0                                                        BKDATA
             C     TEN=1.D+1                                                         BKDATA
             C     ATE=8.D+0                                                         BKDATA
             C     D60=6.D+1                                                         BKDATA
             C     HUND=1.D+2                                                        BKDATA
             C     C480=4.8D+2                                                       BKDATA
             C     STPS=.13053D+0                                                    BKDATA
```



```
             C                                                                       BKDATA
             C     TOPI=6.2831853072D+0                                              BKDATA
             C     DTRA=1.7453292519943D-2                                           BKDATA
             C     DTOM=1.44D+3                                                      BKDATA
             C     TM1=1.D-1                                                         BKDATA
             C     TM4=1.D-4                                                         BKDATA
             C     TM5=1.D-5                                                         BKDATA
             C     TM7=1.D-7                                                         BKDATA
             C     TM8=1.D-8                                                         BKDATA
             C     CMTR=2.90888208D-4                                                BKDATA
             C        =PI/180*60 MINUTES TO RADIANS                                  BKDATA
             C     CKRM=9.6788536D-7                                                 BKDATA
             C        =2/60*10*3443.934 KNOTS TO RAD/2MIN                            BKDATA
 ISN 0025          END                                                               BKDATA
```

/ MAIN / SIZE OF PROGRAM 000008 HEXADECIMAL BYTES PAGE 003

NAME	TAG	TYPE	ADD.	NAME	TAG	TYPE	ADD.	NAME	TAG	TYPE	ADD.	NAME	TAG	TYPE	ADD.
IM	C	I*4	N.R.	KF	C	I*4	N.R.	KM	C	I*4	N.R.	ATE	C	R*8	N.R.
C2K	C	R*8	N.R.	C2M	C	R*8	N.R.	D60	C	R*8	N.R.	I15	C	I*4	N.R.
I30	C	I*4	N.R.	ONE	C	R*8	N.R.	TAW	C	R*8	N.R.	TEN	C	R*8	N.R.
TM1	C	R*8	N.R.	TM4	C	R*8	N.R.	TM5	C	R*8	N.R.	TM7	C	R*8	N.R.
TM8	C	R*8	N.R.	TWO	C	R*8	N.R.	CKRM	C	R*8	N.R.	CMTR	C	R*8	N.R.
CVCG	C	R*8	N.R.	C480	C	R*8	N.R.	DTOM	C	R*8	N.R.	DTRA	C	R*8	N.R.
EFRQ	C	R*8	N.R.	FIVE	C	R*8	N.R.	FOUR	C	R*8	N.R.	HUND	C	R*8	N.R.
IFOR	C	I*4	N.R.	IONE	C	I*4	N.R.	ITWO	C	I*4	N.R.	I365	C	I*4	N.R.
NULL	C	I*4	N.R.	OMGE	C	R*8	N.R.	REFC	C	R*8	N.R.	S7P5	C	R*8	N.R.
THRE	C	R*8	N.R.	TOPI	C	R*8	N.R.	WAVE	C	R*8	N.R.	XOSQ	C	R*8	N.R.
ZERO	C	R*8	N.R.	ZOSQ	C	R*8	N.R.								

***** COMMON INFORMATION *****

NAME OF COMMON BLOCK * COMC* SIZE OF BLOCK 000128 HEXADECIMAL BYTES

VAR. NAME	TYPE	REL. ADDR.	VAR. NAME	TYPE	REL. ADDR.	VAR. NAME	TYPE	REL. ADDR.	VAR. NAME	TYPE	REL. ADDR.
NULL	I*4	N.R.	IONE	I*4	N.R.	ITWO	I*4	N.R.	IFOR	I*4	N.R.
I15	I*4	N.R.	I30	I*4	N.R.	I365	I*4	N.R.	IM	I*4	N.R.
KM	I*4	N.R.	KF	I*4	N.R.	TAW	R*8	N.R.	WAVE	R*8	N.R.
CVCG	R*8	N.R.	EFRQ	R*8	N.R.	OMGE	R*8	N.R.	XOSQ	R*8	N.R.
ZOSQ	R*8	N.R.	ZERO	R*8	N.R.	ONE	R*8	N.R.	TWO	R*8	N.R.
THRE	R*8	N.R.	FOUR	R*8	N.R.	FIVE	R*8	N.R.	ATE	R*8	N.R.
TEN	R*8	N.R.	D60	R*8	N.R.	HUND	R*8	N.R.	C480	R*8	N.R.
S7P5	R*8	N.R.	TOPI	R*8	N.R.	DTRA	R*8	N.R.	DTOM	R*8	N.R.
TM1	R*8	N.R.	TM4	R*8	N.R.	TM5	R*8	N.R.	TM7	R*8	N.R.
TM8	R*8	N.R.	CMTR	R*8	N.R.	CKRM	R*8	N.R.	C2K	R*8	N.R.
C2M	R*8	N.R.	REFC	R*8	N.R.						

OPTIONS IN EFFECT NAME= MAIN,OPT=02,LINECNT=58,SIZE=0000K,

OPTIONS IN EFFECT SOURCE,EBCDIC,NOLIST,NODECK,LOAD,MAP,NOEDIT,ID,NOXREF

STATISTICS SOURCE STATEMENTS = 24 ,PROGRAM SIZE = 8

STATISTICS NO DIAGNOSTICS GENERATED

****** END OF COMPILATION ****** 61K BYTES OF CORE NOT USED

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LEVEL 18 ( SEPT 69 )                    OS/360  FORTRAN H                          DATE  70.196/18.53.55

        COMPILER OPTIONS - NAME=  MAIN,OPT=02,LINECNT=56,SIZE=0000K,
                           SOURCE,EBCDIC,NOLIST,NODECK,LOAD,MAP,NOEDIT,ID,NOXREF
  ISN 0002            SUBROUTINE INPUT                                                 INPUT
               C                                                                       INPUT
               C                                                                       INPUT
  ISN 0003            DOUBLE PRECISION TAW,WAVE,CVCG,EFRQ,OMGE,XOSQ,ZOSQ               INPUT
  ISN 0004            DOUBLE PRECISION ONE,TWO,THRE,FIVE,ATE,TEN,D60,HUND,C480,S7P5    INPUT
  ISN 0005            DOUBLE PRECISION TOPI,DTRA,DTOM,TM1,TM4,TM5,TM8,CMTR,CKRM        INPUT
  ISN 0006            DOUBLE PRECISION ZERO,FOUR,TM7,C2K,C2M,REFC                      INPUT
  ISN 0007            DOUBLE PRECISION DOP,REF,DE,DA,DN,ELAT,ELON,GEOH,ETIM,HEAD,RATE  INPUT
  ISN 0008            DOUBLE PRECISION DTK,TP,XNDT,SOME,SOMD,E,AO,COME,COMD,CI,XLMG    INPUT
  ISN 0009            DOUBLE PRECISION DUM1,DUM2,SI,OFST,DUM3,DUM4,DUM5                INPUT
  ISN 0010            DOUBLE PRECISION DLAT,DLON,SMXE,SELV,FLAT,FLON,FFRQ,RSQ,VN       INPUT
  ISN 0011            DOUBLE PRECISION T,TEMP,A                                        INPUT
  ISN 0012            DOUBLE PRECISION DUM9                                            INPUT
               C                                                                       INPUT
               C---DIMENSIONS                                                          INPUT
  ISN 0013            DIMENSION DOP(8),REF(8),DE(9),DA(9),DN(11),DLAT(9),DLON(9)       INPUT
  ISN 0014            DIMENSION A(3,4)                                                 INPUT
  ISN 0015            DIMENSION DUM9(17)                                               INPUT
               C                                                                       INPUT
               C---COMMON                                                              INPUT
  ISN 0016            COMMON TP,XNDT,SOME,SOMD,E,AO,COME,COMD,CI,XLMG                  INPUT
  ISN 0017            COMMON DUM1,DUM2,SI,OFST,DUM3,DUM4,DUM5,DOP                      INPUT
  ISN 0018            COMMON REF                                                       INPUT
  ISN 0019            COMMON DE,DA,DN,DTK,ELAT,ELON,GEOH,HEAD,RATE,IDAY,MDAY,ETIM      INPUT
  ISN 0020            COMMON DLAT,DLON,SMXE,SELV,FLAT,FLON,FFRQ,RSQ,VN                 INPUT
  ISN 0021            COMMON I,J,K,L,M,N,NLOP,ITER                                     INPUT
  ISN 0022            COMMON T,TEMP,A                                                  INPUT
  ISN 0023            COMMON /COMC/NULL,IONE,IHAD,IFOR,I15,I30,I365,IM,KM,KF           INPUT
  ISN 0024            COMMON /COMC/TAW,WAVE,CVCG,EFRQ,OMGE,XOSQ,ZOSQ,ZERO              INPUT
  ISN 0025            COMMON /COMC/ONE,TWO,THRE,FOUR,FIVE,ATE,TEN,D60,HUND             INPUT
  ISN 0026            COMMON /COMC/C480,S7P5,TOPI,DTRA,DTOM                            INPUT
  ISN 0027            COMMON /COMC/TM1,TM4,TM5,TM7,TM8,CMTR,CKRM,C2K,C2M,REFC          INPUT
               C                                                                       INPUT
               C                                                                       INPUT
  ISN 0028            EQUIVALENCE (TP,DUM9(1))                                         INPUT
               C                                                                       INPUT
  ISN 0029        12 FORMAT(A4,2(I3),I4)                                               INPUT
  ISN 0030        11 FORMAT(5A8)                                                       INPUT
  ISN 0031           READ(5,12) ISTA,ISAT,IDAY,ITIM                                    INPUT
  ISN 0032           IF(ISAT) 30,31,31                                                 INPUT
  ISN 0033        30 WRITE(8,12) ISTA,ISAT,IDAY,ITIM                                   INPUT
  ISN 0034           REWIND 8                                                          INPUT
  ISN 0035           CALL EXIT                                                         INPUT
  ISN 0036        31 READ(5,11) DUM1,DUM2,DUM3,DUM4,DUM5                               INPUT
  ISN 0037           WRITE(8,12) ISTA,ISAT,IDAY,ITIM                                   INPUT
  ISN 0038           WRITE(8,11) DUM1,DUM2,DUM3,DUM4,DUM5                              INPUT
  ISN 0039           READ(5,10) TP,XNDT,SOME,SOMD,E,AO,COME,COMD                       INPUT
                   1   ,CI,XLMG,DUM1,DUM2,SI,OFST,DUM3,DUM4                            INPUT
                   2        ,DUM5 ,(DE(K),K=1,9),(DA(K),K=1,9),                        INPUT
                   3   (DN(K),K=1,11),DTK,GEOH,ELAT,ELON,                              INPUT
                   4  HEAD,RATE,(DOP(K),K=1,8),(REF(K),K=1,8),                         INPUT
                   5  ETIM                                                             INPUT
  ISN 0040        10 FORMAT (1X,D9.0)                                                  INPUT

                                                                                                 PAGE 002

  ISN 0041           DUM1=ELAT*TM4                                                     INPUT
  ISN 0042           I=DUM1/D60                                                        INPUT
  ISN 0043           DUM1=DABS(DUM1-(DBLE(FLOAT(I))*D60))                              INPUT
  ISN 0044           WRITE(8,13) I,DUM1                                                INPUT
  ISN 0045        13 FORMAT(I4,F8.4)                                                   INPUT
  ISN 0046           DUM1=ELON*TM4                                                     INPUT
  ISN 0047           I=DUM1/D60                                                        INPUT
  ISN 0048           DUM1=DABS(DUM1-(DBLE(FLOAT(I))*D60))                              INPUT
  ISN 0049           WRITE(8,13) I,DUM1                                                INPUT
  ISN 0050           WRITE(8,14) GEOH                                                  INPUT
  ISN 0051        14 FORMAT(F9.0)                                                      INPUT
  ISN 0052       114 FORMAT(F10.0,F5.0,F5.0,F3.0,F9.0,F6.0)                            INPUT
  ISN 0053        15 FORMAT(F10.0,F5.0,F5.0,F3.0)                                      INPUT
  ISN 0054        16 FORMAT(F10.0,F3.0)                                                INPUT
  ISN 0055        17 FORMAT(F3.0)                                                      INPUT
  ISN 0056       222 FORMAT(F10.0,F9.0,F6.0)                                           INPUT
  ISN 0057           DO 26 K=1,12                                                      INPUT
  ISN 0058           IF(K-1) 21,21,18                                                  INPUT
  ISN 0059        18 IF(K-8) 22,22,19                                                  INPUT
  ISN 0060        19 IF(K-10) 23,23,20                                                 INPUT
  ISN 0061        20 IF(K-11) 24,24,25                                                 INPUT
  ISN 0062        21 WRITE(8,222) DUM9(K),DOP(K),REF(K)                                INPUT
  ISN 0063           GO TO 26                                                          INPUT
  ISN 0064        22 I=K-1                                                             INPUT
  ISN 0065           WRITE(8,114) DUM9(K),DE(I),DA(I),DN(I),DOP(K),REF(K)              INPUT
  ISN 0066           GO TO 26                                                          INPUT
  ISN 0067        23 I=K-1                                                             INPUT
  ISN 0068           WRITE(8,15) DUM9(K),DE(I),DA(I),DN(I)                             INPUT
  ISN 0069           GO TO 26                                                          INPUT
  ISN 0070        24 I=K-1                                                             INPUT
  ISN 0071           WRITE(8,16) SI,DN(I)                                              INPUT
  ISN 0072           GO TO 26                                                          INPUT
  ISN 0073        25 I=K-1                                                             INPUT
  ISN 0074           WRITE(8,17) DN(I)                                                 INPUT
  ISN 0075        26 CONTINUE                                                          INPUT
  ISN 0076           I=HEAD/D60                                                        INPUT
  ISN 0077           WRITE(8,27) I,RATE                                                INPUT
  ISN 0078        27 FORMAT(I4,F5.1)                                                   INPUT
  ISN 0079           RETURN                                                            INPUT
  ISN 0080           END                                                               INPUT
```

/ INPUT / . SIZE OF PROGRAM 000738 HEXADECIMAL BYTES PAGE 003

NAME	TAG	TYPE	ADD.	NAME	TAG	TYPE	ADD.	NAME	TAG	TYPE	ADD.	NAME	TAG	TYPE	ADD.
A	C	R*6	N.R.	E	S C	R*8	000020	I	SFA C	I*4	0002F8	J	C	I*4	N.R.

K SF	C	I*4	000300	L	C	I*4	N.R.	M	C	I*4	N.R.	N	C	I*4	N.R.
T	C	R*8	N.R.	AO S	C	R*8	000028	CI S	C	R*8	000040	DA SF	C	R*8	000150
DE SF	C	R*8	000108	DN SF	C	R*8	000198	IM	C	I*4	N.R.	KF	C	I*4	N.R.
KM	C	I*4	N.R.	SI SF	C	R*8	000060	TP S	CE	R*8	000000	VN	C	R*8	N.R.
ATE	C	R*8	N.R.	C2K	C	R*8	N.R.	C2M	C	R*8	N.R.	DOP SF	C	R*8	000088
DTK S	C	R*8	0001F0	D60 FA	C	R*8	0000A0	I15	C	I*4	N.R.	I30	C	I*4	N.R.
ONE	C	R*8	N.R.	REF SF	C	R*8	0000C8	RSQ	C	R*8	N.R.	TAW	C	R*8	N.R.
TEN	C	R*8	N.R.	TM1	C	R*8	N.R.	TM4 F	C	R*8	0000E0	TM5	C	R*8	N.R.
TM7	C	R*8	N.R.	TM9	C	R*8	N.R.	TWO	C	R*8	N.R.	CKRM	C	R*8	N.R.
CMTR	C	R*8	N.R.	COMD S	C	R*8	000038	COME S	C	R*8	000030	CVCG	C	R*8	N.R.
C480	C	R*8	N.R.	DLAT	C	R*8	N.R.	DLON	C	R*8	N.R.	DTOM	C	R*8	N.R.
DTRA	C	R*8	N.R.	DUM1 SFA	C	R*8	000050	DUM2 SF	C	R*8	000058	DUM3 SF	C	R*8	000070
DUM4 SF	C	R*8	000078	DUM5 SF	C	R*8	000080	DUM9 F	CE	R*8	000000	EFRQ	C	R*8	N.R.
ELAT SF	C	R*8	0001F8	ELON SF	C	R*8	000200	ETIM S	C	R*8	000228	EXIT SF	XF	R*4	[illegible]
FFRQ	C	R*8	N.R.	FIVE	C	R*8	N.R.	FLAT	C	R*8	N.R.	FLON	C	R*8	N.R.
FOUR	C	R*8	N.R.	GEOM SF	C	R*8	000208	HEAD SF	C	R*8	000210	HUND	C	R*8	N.R.
IDAY SF	C	I*4	000220	IFOR	C	I*4	N.R.	IONE	C	I*4	N.R.	ISAT SF		I*4	[illegible]
ISTA SF		I*4	000110	ITER	C	I*4	N.R.	ITIM SF		I*4	000114	ITWO	C	I*4	N.R.
I365	C	I*4	N.R.	MDAY	C	I*4	N.R.	NDOP	C	I*4	N.R.	NULL	C	I*4	N.R.
OFST S	C	R*8	000068	OMGE	C	R*8	N.R.	RATE SF	C	R*8	000218	REFC	C	R*8	N.R.
SELV	C	R*8	N.R.	SMXE	C	R*8	N.R.	SUMD S	C	R*8	000018	SOME S	C	R*8	000010
STP5	C	R*8	N.R.	TEMP	C	R*8	N.R.	THRE	C	R*8	N.R.	TOPI	C	R*8	N.R.
WAVE	C	R*8	N.R.	XLMG S	C	R*8	000048	XNDT S	C	R*8	000008	XOSQ	C	R*8	N.R.
ZERO	C	R*8	N.R.	ZOSQ	C	R*8	N.R.	INPUT		I*4	000118	IBCOMN F	XF	I*4	[illegible]

***** COMMON INFORMATION *****

NAME OF COMMON BLOCK * * SIZE OF BLOCK 000388 HEXADECIMAL BYTES

VAR. NAME	TYPE	REL. ADDR.	VAR. NAME	TYPE	REL. ADDR.	VAR. NAME	TYPE	REL. ADDR.	VAR. NAME	TYPE	REL. ADDR.
P	R*8	000000	XNDT	R*8	000008	SOME	R*8	000010	SUMD	R*8	000018
E	R*8	000020	AO	R*8	000028	COME	R*8	000030	COMD	R*8	000038
CI	R*8	000040	XLMG	R*8	000048	DUM1	R*8	000050	DUM2	R*8	000058
SI	R*8	000060	OFST	R*8	000068	DUM3	R*8	000070	DUM4	R*8	000078
DUM5	R*8	000080	DOP	R*8	000088	REF	R*8	0000C8	DE	R*8	000108
DA	R*8	000150	DN	R*8	000198	DTK	R*8	0001F0	ELAT	R*8	0001F8
ELON	R*8	000200	GEOM	R*8	000208	HEAD	R*8	000210	RATE	R*8	000218
IDAY	I*4	000220	MDAY	I*4	N.R.	ETIM	R*8	000228	DLAT	R*8	N.R.
DLON	R*8	N.R.	SMXE	R*8	N.R.	SELV	R*8	N.R.	FLAT	R*8	N.R.
FLON	R*8	N.R.	FFRQ	R*8	N.R.	RSQ	R*8	N.R.	VN	R*8	N.R.
I	I*4	0002F8	J	I*4	N.R.	K	I*4	000300	L	I*4	N.R.
M	I*4	N.R.	N	I*4	N.R.	NDOP	I*4	N.R.	ITER	I*4	N.R.
T	R*8	N.R.	TEMP	R*8	N.R.	A	R*8	N.R.			

EQUIVALENCED VARIABLES WITHIN THIS COMMON BLOCK

VARIABLE	OFFSET	VARIABLE	OFFSET	VARIABLE	OFFSET	VARIABLE	OFFSET
DUM9	000000						

NAME OF COMMON BLOCK * COMC* SIZE OF BLOCK 000128 HEXADECIMAL BYTES

VAR. NAME	TYPE	REL. ADDR.	VAR. NAME	TYPE	REL. ADDR.	VAR. NAME	TYPE	REL. ADDR.	VAR. NAME	TYPE	REL. ADDR.
NULL	I*4	N.R.	IONE	I*4	N.R.	ITWO	I*4	N.R.	IFOR	I*4	N.R.
I15	I*4	N.R.	I30	I*4	N.R.	I365	I*4	N.R.	IM	I*4	N.R.
KM	I*4	N.R.	KF	I*4	N.R.	TAW	R*8	N.R.	WAVE	R*8	N.R.
CVCG	R*8	N.R.	EFRQ	R*8	N.R.	OMGE	R*8	N.R.	XOSQ	R*8	N.R.
ZOSQ	R*8	N.R.	ZERO	R*8	N.R.	ONE	R*8	N.R.	TWO	R*8	N.R.
THRE	R*8	N.R.	FOUR	R*8	N.R.	FIVE	R*8	N.R.	ATE	R*8	N.R.
TEN	R*8	N.R.	D60	R*8	0000A0	HUND	R*8	N.R.	C480	R*8	N.R.
STP5	R*8	N.R.	TOPI	R*8	N.R.	DTRA	R*8	N.R.	DTOM	R*8	N.R.
TM1	R*8	N.R.	TM4	R*8	0000E0	TM5	R*8	N.R.	TM7	R*8	N.R.
TM9	R*8	N.R.	CMTR	R*8	N.R.	CKRM	R*8	N.R.	C2K	R*8	N.R.
C2M	R*8	N.R.	REFC	R*8	N.R.						

LABEL	ADDR	LABEL	ADDR	LABEL	ADDR	LABEL	ADDR
10	00019E	11	0001EA	16	00055A	19	000562
20	00056A	21	000578	22	000548	23	000606
24	00064A	25	00067A	26	00069E		

```
*OPTIONS IN EFFECT*      NAME= MAIN,OPT=02,LINECNT=58,SIZE=0000K,

*OPTIONS IN EFFECT*      SOURCE,EBCDIC,NOLIST,NODECK,LOAD,MAP,NOEDIT,ID,NOXREF

*STATISTICS*     SOURCE STATEMENTS =      79 ,PROGRAM SIZE =     18[illegible]

*STATISTICS*  NO  DIAGNOSTICS GENERATED

****** END OF COMPILATION ******                               49K BYTES OF CORE NOT USED
```

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        COMPILER OPTIONS - NAME=  MAIN,OPT=02,LINECNT=58,SIZE=0000K,
                           SOURCE,EBCDIC,NOLIST,NODECK,LOAD,MAP,NOEDIT,ID,NOXREF
ISN 0002           SUBROUTINE CVTM                                              CVTM
           C                                                                    CVTM
           C                                                                    CVTM
           C CONVERT ORBIT PARAMETERS TO COMPUTATIONAL UNITS                    CVTM
           C COMPUTE INCREMENTAL LAT AND LON GIVEN HEADING AND SPEED            CVTM
           C CONVERT CROSS PLANE AND INTERPOLATE                                CVTM
           C RESOLVE TRUE LOCK TIME                                             CVTM
           C CONVERT INITIAL ESTIMATES AND SET INTO COMPUTATION                 CVTM
           C                                                                    CVTM
ISN 0003           DOUBLE PRECISION TAW,WAVF,CVCG,EFRQ,OMGE,XOSQ,ZOSQ           CVTM
ISN 0004           DOUBLE PRECISION ONE,TWO,THRE,FIVE,ATE,TEN,D60,HUND,C480,S7P5 CVTM
ISN 0005           DOUBLE PRECISION TOPI,DTRA,DTOM,TM1,TM4,TM5,TM8,CMTR,CKRM    CVTM
ISN 0006           DOUBLE PRECISION ZERO,FOUR,TM7,C2K,C2M,REFC                  CVTM
ISN 0007           DOUBLE PRECISION DOP,REF,DE,DA,DN,ELAT,ELON,GEOM,STIM,HEAD,RATE CVTM
ISN 0008           DOUBLE PRECISION DTK,TP,XNDT,SOME,SOMD,E,AO,COME,COMD,CI,XLMG CVTM
ISN 0009           DOUBLE PRECISION DUM1,DUM2,SI,OFST,DUM3,DUM4,DUM5            CVTM
ISN 0010           DOUBLE PRECISION DLAT,DLON,SMXE,SELV,FLAT,FLON,FFRQ,RSQ,VN   CVTM
ISN 0011           DOUBLE PRECISION CMSD,CLSD,CPT,TI,P,CP,TEMP,TEMA             CVTM
           C                                                                    CVTM
           C---DIMENSIONS                                                       CVTM
ISN 0012           DIMENSION CPT(5),CP(5)                                       CVTM
ISN 0013           DIMENSION DOP(8),REF(8),DE(9),DA(9),DN(11),DLAT(9),DLON(9)   CVTM
ISN 0014           DIMENSION TEMA(20)                                           CVTM
           C                                                                    CVTM
           C---COMMON                                                           CVTM
ISN 0015           COMMON TP,XNDT,SOME,SOMD,E,AO,COME,COMD,CI,XLMG              CVTM
ISN 0016           COMMON DUM1,DUM2,SI,OFST,DUM3,DUM4,DUM5,DOP                  CVTM
ISN 0017           COMMON REF                                                   CVTM
ISN 0018           COMMON DE,DA,DN,DTK,ELAT,ELON,GEOM,HEAD,RATE,ICAL,MDAY,STIM  CVTM
ISN 0019           COMMON DLAT,DLON,SMXE,SELV,FLAT,FLON,FFRQ,RSQ,VN             CVTM
ISN 0020           COMMON I,J,K,L,M,N,NDOP,IP                                   CVTM
ISN 0021           COMMON TI,P,CP,CPT,CMSD,CLSD,TEMP,TEMA                       CVTM
           C                                                                    CVTM
ISN 0022           COMMON /CONC/NULL,IONE,ITWO,IFOR,I15,I30,I365,IM,KM,KF       CVTM
ISN 0023           COMMON /CONC/TAW,WAVE,CVCG,EFRQ,OMGE,XOSQ,ZOSQ,ZERO          CVTM
ISN 0024           COMMON /CONC/ONE,TWO,THRE,FOUR,FIVE,ATE,TEN,D60,HUND         CVTM
ISN 0025           COMMON /CONC/C480,S7P5,TOPI,DTRA,DTOM                        CVTM
ISN 0026           COMMON /CONC/TM1,TM4,TM5,TM7,TM8,CMTR,CKRM,C2K,C2M,REFC      CVTM
           C                                                                    CVTM
           C CONVERT CONSTANT ORBIT PARAMET.                                    CVTM
           C                                                                    CVTM
ISN 0027           TP=TP*TM5                                                    CVTM
ISN 0028           XNDT=(XNDT+.3D+9)*DTRA*TM8                                   CVTM
ISN 0029           SOME=SOME*DTRA*TM5                                           CVTM
ISN 0030           SOMD=SOMD*DTRA*TM8                                           CVTM
ISN 0031           E=E*TM7                                                      CVTM
           C       AO IS IN METERS                                              CVTM
ISN 0032           COME=COME*DTRA*TM5                                           CVTM
ISN 0033           COMD=COMD*DTRA*TM8                                           CVTM
ISN 0034           CI=CI*TM7                                                    CVTM
ISN 0035           XLMG=XLMG*DTRA*TM5                                           CVTM
ISN 0036           SI=SI*TM7                                                    CVTM
           C                                                                    CVTM
```

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          C---CHECK AND REFRACTION CORRECT THE DOPPLERS                     CVTM
          C----- 0 DOPPLERS NOT USED IN SOLUTION                            CVTM
          C                                                                 CVTM
ISN 0037        NDOP=NULL                                                   CVTM
ISN 0038        DO 30 I=1,IM                                                CVTM
ISN 0039        IF (DOP(I)-C2M) 29,29,21                                    CVTM
ISN 0040     21 IF (REF(I)-C2K) 22,29,22                                    CVTM
ISN 0041     22 DOP(I)=DOP(I)+(C2K-REF(I))*REFC                             CVTM
ISN 0042        NDOP=NDOP+IONE                                              CVTM
ISN 0043        GO TO 30                                                    CVTM
ISN 0044     29 DOP(I)=ZERO                                                 CVTM
ISN 0045     30 CONTINUE                                                    CVTM
          C                                                                 CVTM
          C---CONVERT HEADING AND SPEED                                     CVTM
          C                                                                 CVTM
ISN 0046        HEAD=HEAD*CMTR                                              CVTM
ISN 0047        RATE=RATE*CKRM                                              CVTM
          C                                                                 CVTM
          C CONVERT DE(K),DA(K) AND COMPUTE INCREMENTAL LAT AND LON         CVTM
          C                                                                 CVTM
ISN 0048        DO 1 K=1,KM                                                 CVTM
ISN 0049        DE(K)=DE(K)*DTRA*TM4                                        CVTM
ISN 0050        DA(K)=DA(K)*TEN                                             CVTM
ISN 0051        TEMP=K-KF                                                   CVTM
ISN 0052        TEMP=TEMP*RATE                                              CVTM
ISN 0053        DLON(K)=TEMP*DSIN(HEAD)                                     CVTM
ISN 0054      1 DLAT(K)=TEMP*DCOS(HEAD)                                     CVTM
          C---CONVERT AND SET INITIAL ESTIMATES                             CVTM
ISN 0055        EFRQ=(OFST* 97)*2.4D+4                                      CVTM
ISN 0056        FFRQ=EFRQ                                                   CVTM
ISN 0057        ELAT=ELAT*CMTR*TM4                                          CVTM
ISN 0058        FLAT=ELAT                                                   CVTM
ISN 0059        ELON=ELON*CMTR*TM4                                          CVTM
ISN 0060        FLON=ELON                                                   CVTM
          C---RESOLVE TRUE LOCK TIME                                        CVTM
ISN 0061        IP=STIM/TWO                                                 CVTM
ISN 0062        IP=ITWO*IP                                                  CVTM
ISN 0063        I=IP/I30                                                    CVTM
ISN 0064        I=IP-I30*I                                                  CVTM
ISN 0065        K=TWO*DTK                                                   CVTM
ISN 0066        K=K-I                                                       CVTM
ISN 0067        I=K/I15                                                     CVTM
ISN 0068        K=IP+K-I30*I                                                CVTM
ISN 0069        STIM=K                                                      CVTM
          C---CONVERT CROSS PLANE ELEMENTS                                  CVTM
ISN 0070        I=K/IFOR                                                    CVTM
ISN 0071        K=K-IFOR*I                                                  CVTM
ISN 0072        IP=NULL                                                     CVTM
ISN 0073        L=ITWO                                                      CVTM
ISN 0074        IF (K) 2,3,2                                                CVTM
ISN 0075      2 L=IONE                                                      CVTM
ISN 0076      3 DO 10 I=1,5                                                 CVTM
ISN 0077        CP(I)=ZERO                                                  CVTM
ISN 0078        CLSD=DN(IONE+L)                                             CVTM
ISN 0079        CMSD=DN(L)                                                  CVTM
ISN 0080        IF (CMSD) 9,11,11                                           CVTM
```



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ISN 0081     11 IF (CLSD) 9,4,4                                             CVTM
ISN 0082      4 CMSD=CMSD-FIVE                                              CVTM
ISN 0083        IF (CMSD) 5,8,8                                             CVTM
ISN 0084      5 CLSD=-CLSD                                                  CVTM
ISN 0085        IF (CMSD+FIVE) 8,6,8                                        CVTM
ISN 0086      6 CMSD=ZERO                                                   CVTM
ISN 0087      8 IP=IP+IONE                                                  CVTM
ISN 0088        CP(IP)=HUND*CMSD+TEN*CLSD                                   CVTM
ISN 0089        CPT(IP)=L                                                   CVTM
ISN 0090      9 L=L+ITWO                                                    CVTM
ISN 0091     10 CONTINUE                                                    CVTM
          C---INTERPOLATE FOR MISSING CROSS PLANE ELEMENTS                  CVTM
ISN 0092        TI=TWO                                                      CVTM
ISN 0093        DO 20 K=1,KM                                                CVTM
ISN 0094        DN(K)=ZERO                                                  CVTM
ISN 0095        IF (IP-ITWO) 20,20,31                                       CVTM
ISN 0096     31 ITA=IONE                                                    CVTM
ISN 0097        I=CPT(1)                                                    CVTM
ISN 0098        J=CPT(IP)                                                   CVTM
ISN 0099        J=J-IFOR                                                    CVTM
ISN 0100        IF (K-I) 16,16,12                                           CVTM
ISN 0101     12 ITA=IP-ITWO                                                 CVTM
ISN 0102        IF (K-J) 13,16,16                                           CVTM
ISN 0103     13 ITA=K/ITWO                                                  CVTM
ISN 0104     16 DO 19 L=1,3                                                 CVTM
ISN 0105        J=L+ITA-IONE                                                CVTM
ISN 0106        P=ONE                                                       CVTM
ISN 0107        DO 18 M=1,3                                                 CVTM
ISN 0108        I=M+ITA-IONE                                                CVTM
ISN 0109        IF (I-J) 17,18,17                                           CVTM
ISN 0110     17 P=P*(TI-CPT(I))/(CPT(J)-CPT(I))                             CVTM
ISN 0111     18 CONTINUE                                                    CVTM
ISN 0112     19 DN(K)=DN(K)+P*CP(J)                                         CVTM
ISN 0113     20 TI=TI+ONE                                                   CVTM
ISN 0114        RETURN                                                      CVTM
ISN 0115        END                                                         CVTM
```

/ CVTM / SIZE OF PROGRAM 0006F2 HEXADECIMAL BYTES PAGE 004

NAME	TAG	TYPE	ADD.	NAME	TAG	TYPE	ADD.	NAME	TAG	TYPE	ADD.	NAME	TAG	TYPE	ADD.
E	SF C	R*8	000020	I	SF C	I*4	0002F8	J	SF C	I*4	0002FC	K	SF C	I*4	000300
L	SF C	I*4	000304	M	SF C	I*4	000308	N	C	I*4	N.R.	P	SF C	R*8	000320
AO	C	R*8	N.R.	CI	SF C	R*8	000040	CP	SF C	R*8	000328	DA	SF C	R*8	000150
DE	SF C	R*8	000108	DN	SF C	R*8	000198	IM	F C	I*4	00001C	IP	SF C	I*4	000314
KF	F C	I*4	000024	KM	F C	I*4	000020	SI	SF C	R*8	000060	TI	SF C	R*8	000318
TP	SF C	R*8	000000	VN	C	R*8	N.R.	ATE	C	R*8	N.R.	CPT	SF C	R*8	000350
C2K	F C	R*8	000110	C2M	C	R*8	000118	DOP	SF C	R*8	000088	DTK	F C	R*8	0001F0
D60	C	R*8	N.R.	ITA	SF	I*4	0000AC	I15	F C	I*4	000010	I30	F C	I*4	000014
ONE	F C	R*8	000068	REF	F C	R*8	0000C8	RSQ	C	R*8	N.R.	TAW	C	R*8	N.R.
TEN	F C	R*8	000098	TM1	C	R*8	N.R.	TM4	F C	R*8	0000E0	TM5	F C	R*8	0000E8
TM7	F C	R*8	0000F0	TM8	F C	R*8	0000F8	TWO	F C	R*8	000070	CKRM	F C	R*8	000108
CLSD	SF C	R*8	000380	CMSD	SF C	R*8	000378	CMTR	F C	R*8	000100	COMD	SF C	R*8	000038
CONE	SF C	R*8	000030	CVCG	C	R*8	N.R.	CVTM		R*4	000080	C480	C	R*8	N.R.
DLAT	S C	R*8	000230	DLON	S C	R*8	000278	DTUM	C	R*8	N.R.	DTRA	F C	R*8	0000C8
DUM1	C	R*8	N.R.	DUM2	C	R*8	N.R.	DUM3	C	R*8	N.R.	DUM4	C	R*8	N.R.
DUM5	C	R*8	N.R.	EFRQ	SF C	R*8	000040	ELAT	SF C	R*8	0001F8	ELON	SF C	R*8	000200
FFRQ	S C	R*8	0002E0	FIVE	F C	R*8	000088	FLAT	S C	R*8	000200	FLON	S C	R*8	000208
FOUR	C	R*8	N.R.	GEOH	C	R*8	N.R.	HEAD	SFA C	R*8	000210	HUND	F C	R*8	0000A8
IDAY	C	I*4	N.R.	IFOR	F C	I*4	00000C	IONE	F C	I*4	000004	ITWO	F C	I*4	000008
I365	C	I*4	N.R.	MDAY	C	I*4	N.R.	NOOP	SF C	I*4	000310	NULL	F C	I*4	000000
OFST	F C	R*8	000068	OMGE	C	R*8	N.R.	RATE	SF C	R*8	000218	REFC	F C	R*8	000120
SELV	C	R*8	N.R.	SMXE	C	R*8	N.R.	SOMD	SF C	R*8	000018	SOME	SF C	R*8	000010
STIM	SF C	R*8	000228	STPS	C	R*8	N.R.	TEMA	C	R*8	N.R.	TEMP	SF C	R*8	000388
THRE	C	R*8	N.R.	TOPI	C	R*8	N.R.	WAVE	C	R*8	N.R.	XLMG	SF C	R*8	000048
XNDT	SF C	R*8	000008	XOSG	C	R*8	N.R.	ZERO	F C	R*8	000060	ZOSG	C	R*8	N.R.
DCOS	XF	R*8	000000	DSIN	XF	R*8	000000								

***** COMMON INFORMATION *****

NAME OF COMMON BLOCK * * SIZE OF BLOCK 000430 HEXADECIMAL BYTES

VAR. NAME	TYPE	REL. ADDR.	VAR. NAME	TYPE	REL. ADDR.	VAR. NAME	TYPE	REL. ADDR.	VAR. NAME	TYPE	REL. ADDR.
TP	R*8	000000	XNDT	R*8	000008	SOME	R*8	000010	SOMD	R*8	000018
E	R*8	000020	AO	R*8	N.R.	CONE	R*8	000030	COMD	R*8	000038
CI	R*8	000040	XLMG	R*8	000048	DUM1	R*8	N.R.	DUM2	R*8	N.R.
SI	R*8	000060	OFST	R*8	000068	DUM3	R*8	N.R.	DUM4	R*8	N.R.
DUM5	R*8	N.R.	DOP	R*8	000088	REF	R*8	0000C8	DE	R*8	000108
DA	R*8	000150	DN	R*8	000198	DTK	R*8	0001F0	ELAT	R*8	0001F8
ELON	R*8	000200	GEOH	R*8	N.R.	HEAD	R*8	000210	RATE	R*8	000218
IDAY	I*4	N.R.	MDAY	I*4	N.R.	STIM	R*8	000228	DLAT	R*8	000230
DLON	R*8	000278	SMXE	R*8	N.R.	SELV	R*8	N.R.	FLAT	R*8	000200
FLON	R*8	000208	FFRQ	R*8	0002E0	RSQ	R*8	N.R.	VN	R*8	N.R.
I	I*4	0002F8	J	I*4	0002FC	K	I*4	000300	L	I*4	000304
M	I*4	000308	N	I*4	N.R.	NOOP	I*4	000310	IP	I*4	000314
TI	R*8	000318	P	R*8	000320	CP	R*8	000328	CPT	R*8	000350
CMSD	R*8	000378	CLSD	R*8	000380	TEMP	R*8	000388	TEMA	R*8	N.R.

NAME OF COMMON BLOCK * COMC* SIZE OF BLOCK 000128 HEXADECIMAL BYTES

VAR. NAME	TYPE	REL. ADDR.	VAR. NAME	TYPE	REL. ADDR.	VAR. NAME	TYPE	REL. ADDR.	VAR. NAME	TYPE	REL. ADDR.
NULL	I*4	000000	IONE	I*4	000004	ITWO	I*4	000008	IFOR	I*4	00000C
I15	I*4	000010	I30	I*4	000014	I365	I*4	N.R.	IM	I*4	00001C

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KM	I*4	000020	KF	I*4	000024	TAW	R*8	N.R.	WAVE	R*8	N.R.
CVCG	R*8	N.R.	EFRQ	R*8	000040	OMGE	R*8	N.R.	XOSG	R*8	N.R.
ZOSG	R*8	N.R.	ZERO	R*8	000060	ONE	R*8	000068	TWO	R*8	000070
THRE	R*8	N.R.	FOUR	R*8	N.R.	FIVE	R*8	000088	ATE	R*8	N.R.
TEN	R*8	000098	D60	R*8	N.R.	HUND	R*8	0000A8	C480	R*8	N.R.
STPS	R*8	N.R.	TOPI	R*8	N.R.	DTRA	R*8	0000C8	DTCM	R*8	N.R.
TM1	R*8	N.R.	TM4	R*8	0000E0	TM5	R*8	0000E8	TM7	R*8	0000F0
TM8	R*8	0000F8	CMTR	R*8	000100	CKRM	R*8	000108	C2K	R*8	000110
C2M	R*8	000118	REFC	R*8	000120						

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LABEL   ADDR            LABEL   ADDR            LABEL   ADDR            LABEL   ADDR            PAGE 20?

   21   0001EC             22   0001FE             29   000214             30   00021C
    1   00020E              2   00040E              3   000412             11   000486
    4   000490              5   000498              6   0004AC              8   0004B0
    9   0004F2             10   0004FA             31   0005A6             12   00055F
   13   000502             16   0005F2             17   00063E             18   00065A
   19   00066A             20   000696

*OPTIONS IN EFFECT*     NAME=  MAIN,OPT=02,LINECNT=58,SIZE=0000K,

*OPTIONS IN EFFECT*     SOURCE,EBCDIC,NOLIST,NODECK,LOAD,MAP,NOEDIT,ID,NOXREF

*STATISTICS*     SOURCE STATEMENTS =     114 ,PROGRAM SIZE =     1778

*STATISTICS*  0   DIAGNOSTICS GENERATED

****** END OF COMPILATION ******                                 49? BYTES OF CORE NOT USED
```

LEVEL 18 (SEPT 69)   OS/360 FORTRAN H   DATE 70.196/18.53.47

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          COMPILER OPTIONS - NAME=  MAIN,OPT=02,LINECNT=58,SIZE=0000K,
                             SOURCE,EBCDIC,NOLIST,NODECK,LOAD,MAP,NOEDIT,ID,NOXREF
  ISN 0002          SUBROUTINE SATC                                                  SATC
              C                                                                      SATC
              C-USES SXYZ TO COMPUTE SATELLITE COORDINATES                           SATC
              C DRIVER TO SET TIME AND VARIABLE PARAMETERS AND STORING PARAMETER K    SATC
              C                                                                      SATC
  ISN 0003          DOUBLE PRECISION TAW,WAVE,CVCG,EFRQ,OMGE,XOSQ,ZOSQ               SATC
  ISN 0004          DOUBLE PRECISION ONE,TWO,THRE,FIVE,ATE,TEN,D60,HUND,C480,S7P5    SATC
  ISN 0005          DOUBLE PRECISION TOPI,DTRA,DTOM,TM1,TM4,TM5,TM8,CMTR,CKRM        SATC
  ISN 0006          DOUBLE PRECISION ZERO,FOUR,TM7,C2K,C2M,REFC                      SATC
  ISN 0007          DOUBLE PRECISION DOP,DJM,DE,DA,DN,ELAT,ELON,GEOH,STIM,HEAD,RATE  SATC
  ISN 0008          DOUBLE PRECISION DTK,TP,XNDT,SOME,SOMD,E,AO,COME,COMD,CI,XLNG    SATC
  ISN 0009          DOUBLE PRECISION DUM1,DUM2,SI,OFST,DUM3,DUM4,DUM5                SATC
  ISN 0010          DOUBLE PRECISION DLAT,DLON,SMXE,SELV,FLAT,FLON,FFRQ,RSQ,VN       SATC
  ISN 0011          DOUBLE PRECISION DEK,DAK,DNK                                     SATC
  ISN 0012          DOUBLE PRECISION T,TEMP                                          SATC
              C                                                                      SATC
              C---DIMENSION                                                          SATC
  ISN 0013          DIMENSION DOP(8),DJM(5),DE(9),DA(9),DN(11),DLAT(9),DLON(9.       SATC
              C                                                                      SATC
              C---COMMON                                                             SATC
  ISN 0014          COMMON TP,XNDT,SOME,SOMD,E,AO,COME,COMD,CI,XLNG                  SATC
  ISN 0015          COMMON DUM1,DUM2,SI,OFST,DUM3,DUM4,DUM5,DOP                      SATC
  ISN 0016          COMMON DEK,DAK,DNK                                               SATC
  ISN 0017          COMMON DUM                                                       SATC
  ISN 0018          COMMON DE,DA,DN,DTK,FLAT,ELON,GEOH,HEAD,RATE,IDAY,MDAY,STIM      SATC
  ISN 0019          COMMON DLAT DLON,SMXE,SEL ,FLAT,FLON,FFRQ,RSQ,VN                 SATC
  ISN 0020          COMMON I,J,K,L,M,N,MDOP,ITEP                                     SATC
  ISN 0021          COMMON T,TEMP                                                    SATC
              C                                                                      SATC
  ISN 0022          COMMON /COMC/NULL,ICNE,ITWO,IFOR,I15,I30,I365,IM,KM,KF           SATC
  ISN 0023          COMMON /COMC/TAW,WAVE,CVCG,EFRQ,OMGE,XOSQ,ZOSQ,ZERO              SATC
  ISN 0024          COMMON /COMC/ONE,TWO,THRE,FOUR,FIVE,ATE,TEN,D60,HUND             SATC
  ISN 0025          COMMON /COMC/C480,S7P5,TOPI,DTRA,DTOM                            SATC
  ISN 0026          COMMON /COMC/TM1,TM4,TM5,TM7,TM8,CMTR,CKRM,C2K,C2K,REFC          SATC
              C                                                                      SATC
              C---COMPUTE TIME SINCE PERIGEE                                         SATC
  ISN 0027          T=STIM-TP                                                        SATC
  ISN 0028          IF (T+C480) 1,1,2                                                SATC
  ISN 0029        1 T=T+DTOM                                                         SATC
  ISN 0030          GO TO 4                                                          SATC
  ISN 0031        2 IF (T-DTOM*TOPI/XNDT) 4,3,3                                      SATC
  ISN 0032        3 T=T-DTOM                                                         SATC
  ISN 0033        4 DO 5 K=1,KM                                                      SATC
  ISN 0034          DEK=DE(K)                                                        SATC
  ISN 0035          DAK=DA(K)                                                        SATC
  ISN 0036          DNK=DN(K)                                                        SATC
  ISN 0037          CALL SXYZ                                                        SATC
  ISN 0038        5 T=T+TWO                                                          SATC
  ISN 0039          RETURN                                                           SATC
  ISN 0040          END                                                              SATC
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/ SATC / SIZE OF PROGRAM 000264 HEXADECIMAL BYTES PAGE 002

NAME	TAG	TYPE	ADD.	NAME	TAG	TYPE	ADD.	NAME	TAG	TYPE	ADD.	NAME	TAG	TYPE	ADD.
E	C	R*8	N.R.	I	C	I*4	N.R.	J	C	I*4	N.R.	K SF	C	I*4	[illegible]
L	C	I*4	N.R.	M	C	I*4	N.R.	N	C	I*4	N.R.	T SF	C	R*8	[illegible]
AO	C	R*8	N.R.	CI	C	R*8	N.R.	DA F	C	R*8	000150	DE F	C	R*8	[illegible]
DN F	C	R*8	000198	IM	C	I*4	N.R.	KF	C	I*4	N.R.	[illegible] F	C	I*4	[illegible]
SI	C	R*8	N.R.	TP F	C	R*8	000100	VN	C	R*8	N.R.	ATE	C	R*8	N.R.
C2K	C	R*8	N.R.	C2M	C	R*8	N.R.	DAK S	C	R*8	000000	DEK S	C	R*8	[illegible]
DNK S	C	R*8	000006	DOP	C	R*8	N.R.	DTK	C	R*8	N.R.	DUM	C	R*8	N.R.
D60	C	R*8	N.R.	I15	C	I*4	N.R.	I30	C	I*4	N.R.	ONE	C	R*8	N.R.
RSQ	C	R*8	N.R.	TAW	C	R*8	N.R.	TEN	C	R*8	N.R.	TM1	C	R*8	N.R.
TM4	C	R*8	N.R.	TM5	C	R*8	N.R.	TM7	C	R*8	N.R.	TM8	C	R*8	N.R.
TWO F	C	R*8	000070	CKRM	C	R*8	N.R.	CMTR	C	R*8	N.R.	[illegible]	C	R*8	N.R.
COME	C	R*8	N.R.	CVCG	C	R*8	N.R.	C480	C	R*8	[illegible]	[illegible]	C	R*8	[illegible]
DLON	C	R*8	N.R.	DTOM F	C	R*8	000000	DTRA	C	R*8	N.R.	[illegible]	C	R*8	[illegible]
DUM2	C	R*8	N.R.	DUM3	C	R*8	N.R.	DUM4	C	R*8	N.R.	[illegible]	C	R*8	[illegible]
EFRQ	C	R*8	N.R.	ELAT	C	R*8	N.R.	ELON	C	R*8	N.R.	[illegible]	C	R*8	[illegible]
FIVE	C	R*8	N.R.	FLAT	C	R*8	N.R.	FLON	C	R*8	N.R.	[illegible]	C	R*8	[illegible]
GEOH	C	R*8	N.R.	HEAD	C	R*8	N.R.	HUND	C	R*8	N.R.	IDAY	C	I*4	N.R.
IFOR	C	I*4	N.R.	ICNE	C	I*4	N.R.	ITEP	C	I*4	N.R.	ITWO	C	I*4	N.R.
I365	C	I*4	N.R.	MDAY	C	I*4	N.R.	MDOP	C	I*4	N.R.	NULL	C	I*4	N.R.
OFST	C	R*8	N.R.	OMGE	C	R*8	N.R.	RATE	C	R*8	N.R.	REFC	C	R*8	N.R.
SATC		R*4	00007C	SELV	C	R*8	N.R.	SMXE	C	R*8	N.R.	SOMD	C	R*8	N.R.
SOME	C	R*8	N.R.	STIM F	C	R*8	000228	SXYZ SF	XF	R*4	[illegible]	S7P5	C	R*8	N.R.
TEMP	C	R*8	N.R.	THRE	C	R*8	N.R.	TOPI	C	R*8	[illegible]	WAVE	C	R*8	N.R.
XLNG	C	R*8	N.R.	XNDT	C	R*8	000000	XOSQ	C	R*8	N.R.	ZERO	C	R*8	N.R.
ZOSQ	C	R*8	N.R.												

***** COMMON INFORMATION *****

NAME OF COMMON BLOCK * * SIZE OF BLOCK 000328 HEXADECIMAL BYTES

VAR. NAME	TYPE	REL. ADDR.	VAR. NAME	TYPE	REL. ADDR.	VAR. NAME	TYPE	REL. ADDR.	VAR. NAME	TYPE	REL. ADDR.
TP	R*8	000000	XNDT	R*8	000008	SOME	R*8	[illegible]	[illegible]	[illegible]	[illegible]
E	R*8	N.R.	AO	R*8	N.R.	COME	R*8	[illegible]	[illegible]	[illegible]	[illegible]
CI	R*8	N.R.	XLNG	R*8	N.R.	DUM1	R*8	[illegible]	[illegible]	[illegible]	[illegible]
SI	R*8	N.R.	OFST	R*8	N.R.	DUM3	R*8	[illegible]	[illegible]	[illegible]	[illegible]
DUM5	R*8	N.R.	DOP	R*8	N.R.	DEK	R*8	[illegible]	[illegible]	[illegible]	[illegible]
DNK	R*8	000018	DUM	R*8	N.R.	DE	R*8	[illegible]	[illegible]	[illegible]	[illegible]
DN	R*8	000198	DTK	R*8	N.R.	FLAT	R*8	[illegible]	[illegible]	[illegible]	[illegible]
GEOH	R*8	N.R.	HEAD	R*8	N.R.	RATE	R*8	[illegible]	IDAY	I*4	[illegible]
MDAY	I*4	N.R.	STIM	R*8	000228	DLAT	R*8	[illegible]	[illegible]	[illegible]	[illegible]
SMXE	R*8	N.R.	SELV	R*8	N.R.	FLAT	R*8	[illegible]	[illegible]	[illegible]	[illegible]
FFRQ	R*8	N.R.	RSQ	R*8	N.R.	VN	R*8	[illegible]	I	I*4	[illegible]
J	I*4	N.R.	K	I*4	000300	L	I*4	[illegible]		I*4	[illegible]
N	I*4	N.R.	MDOP	I*4	N.R.	ITEP	I*4	[illegible]	T	[illegible]	[illegible]
TEMP	R*8	N.R.									

NAME OF COMMON BLOCK * CONC* SIZE OF BLOCK 0001Z0 HEXADECIMAL BYTES

VAR. NAME	TYPE	REL. ADDR.	VAR. NAME	TYPE	REL. ADDR.	VAR. NAME	TYPE	REL. ADDR.	VAR. NAME	TYPE	REL. ADDR.
NULL	I*4	N.R.	IONE	I*4	N.R.	ITWO	I*4	N.R.	IFOR	I*4	N.R.
I15	I*4	N.R.	I30	I*4	N.R.	I365	I*4	N.R.	IM	I*4	N.R.
KM	I*4	000C20	KF	I*4	N.R.	TAM	R*8	N.R.	WAVE	R*8	N.R.

PAGE 003

CVCG	R*8	N.R.	EFRQ	R*8	N.R.	OMGE	R*8	N.R.	XOSQ	R*8	N.R.
ZOSQ	R*8	N.R.	ZERO	R*8	N.R.	ONE	R*8	N.R.	TWO	R*8	000070
THRE	R*8	N.R.	FOUR	R*8	N.R.	FIVE	R*8	N.R.	ATE	R*8	N.R.
TEN	R*8	N.R.	D60	R*8	N.R.	HUND	R*8	N.R.	C480	R*8	0000B0
S7P5	R*8	N.R.	TOPI	R*8	0000C0	DTRA	R*8	N.R.	DTCM	R*8	000090
TM1	R*8	N.R.	TM4	R*8	N.R.	TM5	R*8	N.R.	TM7	R*8	N.R.
TM8	R*8	N.R.	CMTR	R*8	N.R.	CKRM	R*8	N.R.	C2K	R*8	N.R.
C2M	R*8	N.R.	REFC	R*8	N.R.						

```
LABEL   ADDR            LABEL   ADDR            LABEL   ADDR            LABEL   ADDR            PAGE 004

    1  0000C2               2  0000D2               3  0000EC               4  0000F0
    5  00011E

*OPTIONS IN EFFECT*     NAME=  MAIN,OPT=02,LINECNT=58,SIZE=0000K,

*OPTIONS IN EFFECT*     SOURCE,EBCDIC,NOLIST,NODECK,LOAD,MAP,NOEDIT,ID,NOXREF

*STATISTICS*    SOURCE STATEMENTS =      39 ,PROGRAM SIZE =       356

*STATISTICS*  NO  DIAGNOSTICS GENERATED

****** END OF COMPILATION ******                                        61K BYTES OF CORE NOT USED
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      COMPILER OPTIONS - NAME=  MAIN,OPT=02,LINECNT=58,SIZE=0000K,
                        SOURCE,EBCDIC,NOLIST,NODECK,LOAD,MAP,NOEDIT,ID,NOXREF
ISN 0002             SUBROUTINE SXYZ                                                   SXYZ
               C                                                                       SXYZ
               C COMPUTE SATELLITE COORDINATES FOR TIME T CORRESPONDING TO POINT K     SXYZ
               C                                                                       SXYZ
ISN 0003             DOUBLE PRECISION TAW,WAVE,CVCG,EFRQ,OMGE,XOSQ,ZOSQ                SXYZ
ISN 0004             DOUBLE PRECISION UNE,TWO,THRE,FIVE,ATE,TEN,D60,HUND,C480,S7P5     SXYZ
ISN 0005             DOUBLE PRECISION TOPI,DTRA,DTOM,TM1,TM4,TM5,TM8,CMTR,CKRM         SXYZ
ISN 0006             DOUBLE PRECISION ZERO,FOUR,TM7,C2K,C2M,REFC                       SXYZ
ISN 0007             DOUBLE PRECISION DOP,XS,YS,ZS,ELAT,ELON,GEOH,STIM,HEAD,RATE       SXYZ
ISN 0008             DOUBLE PRECISION DTK,TP,XNDT,SOME,SOMD,E,AO,COME,COMD,CI,XLMG     SXYZ
ISN 0009             DOUBLE PRECISION DUM1,DUM2,SI,OFST,DUM3,DUM4,DUM5                 SXYZ
ISN 0010             DOUBLE PRECISION DUM,T,TEMP                                       SXYZ
ISN 0011             DOUBLE PRECISION DLAT,DLON,SMXE,SELV,FLAT,FLON,FFRQ,RSQ,VN        SXYZ
ISN 0012             DOUBLE PRECISION DEK,DAK,DNK                                      SXYZ
ISN 0013             DOUBLE PRECISION XMK,EK,AK,UK,VK,WK,CWK,SWK,XKP,YKP,BK,CBK,SBK    SXYZ
               C                                                                       SXYZ
               C---DIMENSION                                                           SXYZ
ISN 0014             DIMENSION DOP(8),XS(9),YS(9),ZS(11),DLAT(9),DLON(9)               SXYZ
ISN 0015             DIMENSION DUM(4)                                                  SXYZ
               C                                                                       SXYZ
               C---COMMON                                                              SXYZ
ISN 0016             COMMON TP,XNDT,SOME,SOMD,E,AO,COME,COMD,CI,XLMG                   SXYZ
ISN 0017             COMMON DUM1,DUM2,SI,OFST,DUM3,DUM4,DUM5,DOP                       SXYZ
ISN 0018             COMMON DEK,DAK,DNK,XMK,DUM                                        SXYZ
ISN 0019             COMMON XS,YS,ZS,DTK,ELAT,ELON,GEOH,HEAD,RATE,IDAY,MDAY,STIM       SXYZ
ISN 0020             COMMON DLAT,DLON,SMXF,SELV,FLAT,FLON,FFRQ,RSQ,VN                  SXYZ
ISN 0021             COMMON I,J,K,L,M,N,NDOP,ITER                                      SXYZ
ISN 0022             COMMON T,TEMP,EK,AK,UK,VK,WK,CWK,SWK,XKP,YKP,BK,CBK,SBK           SXYZ
               C                                                                       SXYZ
ISN 0023             COMMON /CONC/NULL,IONE,ITWO,IFOR,I15,I30,I365,IM,KM,KF            SXYZ
ISN 0024             COMMON /CONC/TAW,WAVE,CVCG,EFRQ,OMGE,XOSQ,ZOSQ,ZERO               SXYZ
ISN 0025             COMMON /CONC/ONE,TWO,THRE,FOUR,FIVE,ATE,TEN,D60,HUND              SXYZ
ISN 0026             COMMON /CONC/C480,S7P5,TOPI,DTRA,DTOM                             SXYZ
ISN 0027             COMMON /CONC/TM1,TM4,TM5,TM7,TM8,CMTR,CKRM,C2K,C2M,REFC           SXYZ
               C                                                                       SXYZ
ISN 0028             XMK=T*XNDT                                                        SXYZ
ISN 0029             EK=E*DSIN(XMK)+XMK+DEK                                            SXYZ
ISN 0030             AK=AO+DAK                                                         SXYZ
ISN 0031             VK=AK*DSIN(EK)                                                    SXYZ
ISN 0032             UK=(DCOS(EK)-E)*AK                                                SXYZ
ISN 0033             WK=SOME-T*SOMD                                                    SXYZ
ISN 0034             CWK=DCOS(WK)                                                      SXYZ
ISN 0035             SWK=DSIN(WK)                                                      SXYZ
ISN 0036             XKP=UK*CWK-VK*SWK                                                 SXYZ
ISN 0037             YKP=VK*CWK+UK*SWK                                                 SXYZ
ISN 0038             BK=(COMD-OMGE)*T+COME-                                            SXYZ
ISN 0039             CBK=DCOS(BK)                                                      SXYZ
ISN 0040             SBK=DSIN(BK)                                                      SXYZ
ISN 0041             TEMP=YKP*CI-DNK*SI                                                SXYZ
ISN 0042             XS(K)=XKP*CBK-TEMP*SBK                                            SXYZ
ISN 0043             YS(K)=XKP*SBK+TEMP*CBK                                            SXYZ
ISN 0044             ZS(K)=YKP*SI+DNK*CI                                               SXYZ
ISN 0045             RETURN                                                            SXYZ
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ISN 0046             END                                                               SXYZ
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NAME	TAG	TYPE	ADD.	NAME	TAG	TYPE	ADD.	NAME	TAG	TYPE	ADD.	NAME	TAG	TYPE	ADD.
E	F C	R*8	000020	I	C	I*4	N.R.	J	C	I*4	N.R.	K	F C	I*4	000300
L	C	I*4	N.R.	M	C	I*4	N.R.	N	C	I*4	N.R.	T	F C	R*8	000318
AK	SF C	R*8	000330	AO	F C	R*8	000028	BK	SFA C	R*8	000370	CI	F C	R*8	000040
EK	SFA C	R*8	000328	IM	C	I*4	N.R.	KF	C	I*4	N.R.	KM	C	I*4	N.R.
SI	F C	R*8	000060	TP	C	R*8	N.R.	UK	SF C	R*8	000338	VK	SF C	R*8	000340
VN	C	R*8	N.R.	WK	SFA C	R*8	000348	XS	S C	R*8	000108	YS	S C	R*8	000150
ZS	S C	R*8	000198	ATE	C	R*8	N.R.	CBK	SF C	R*8	000378	CMK	SF C	R*8	000350
C2K	C	R*8	N.R.	C2M	C	R*8	N.R.	DAK	F C	R*8	0000D0	DEK	F C	R*8	0000C8
DNK	F C	R*8	000008	DOP	C	R*8	N.R.	DTK	C	R*8	N.R.	DUM	C	R*8	N.R.
D60	C	R*8	N.R.	I15	C	I*4	N.R.	I30	C	I*4	N.R.	ONE	C	R*8	N.R.
RSQ	C	R*8	N.R.	SBK	SF C	R*8	000380	SWK	SF C	R*8	000358	TAN	C	R*8	N.R.
TEN	C	R*8	N.R.	TP1	C	R*8	N.R.	TM4	C	R*8	N.R.	TM5	C	R*8	N.R.
TM7	C	R*8	N.R.	TM8	C	R*8	N.R.	TWO	C	R*8	N.R.	XKP	SF C	R*8	000360
XMK	SFA C	R*8	0000E0	YKP	SF C	R*8	000368	CKRM	C	R*8	N.R.	CMTR	C	R*8	N.R.
COND	F C	R*8	000038	COME	F C	R*8	000030	CVCS	C	R*8	N.R.	C460	C	R*8	N.R.
DLAT	C	R*8	N.R.	DLON	C	R*8	N.R.	DTOM	C	R*8	N.R.	DTRA	C	R*8	N.R.
DUM1	C	R*8	N.R.	DUM2	C	R*8	N.R.	DUM3	C	R*8	N.R.	DUM4	C	R*8	N.R.
DUM5	C	R*8	N.R.	EFRQ	C	R*8	N.R.	ELAT	C	R*8	N.R.	ELON	C	R*8	N.R.
FFRQ	C	R*8	N.R.	FIVE	C	R*8	N.R.	FLAT	C	R*8	N.R.	FLON	C	R*8	N.R.
FOUR	C	R*8	N.R.	GEOM	C	R*8	N.R.	HEAD	C	R*8	N.R.	HUND	C	R*8	N.R.
IDAY	C	I*4	N.R.	IFOR	C	I*4	N.R.	IONE	C	I*4	N.R.	ITER	C	I*4	N.R.
ITWO	C	I*4	N.R.	I365	C	I*4	N.R.	MDAY	C	I*4	N.R.	NOOP	C	I*4	N.R.
NULL	C	I*4	N.R.	OFST	C	R*8	N.R.	OMGE	F C	R*8	000048	RATE	C	R*8	N.R.
REFC	C	R*8	N.R.	SELV	C	R*8	N.R.	SMXE	C	R*8	N.R.	SOMD	F C	R*8	000018
SOME	F C	R*8	000010	STIM	C	R*8	N.R.	SXYZ		R*4	000090	STPS	C	R*8	N.R.
TEMP	SF C	R*8	000320	THRE	C	R*8	N.R.	TOPI	C	R*8	N.R.	WAVE	C	R*8	N.R.
XLMG	F C	R*8	000048	XNDT	F C	R*8	000008	XOSQ	C	R*8	N.R.	ZERO	C	R*8	N.R.
ZOSQ	C	R*8	N.R.	DCOS	XF	R*8	000000	DSIN	XF	R*8	000000				

***** COMMON INFORMATION *****

NAME OF COMMON BLOCK * * SIZE OF BLOCK 000388 HEXADECIMAL BYTES

VAR. NAME	TYPE	REL. ADDR.	VAR. NAME	TYPE	REL. ADDR.	VAR. NAME	TYPE	REL. ADDR.	VAR. NAME	TYPE	REL. ADDR.
TP	R*8	N.R.	XNDT	R*8	000008	SOME	R*8	000010	SOMD	R*8	000018
E	R*8	000020	AO	R*8	000028	COME	R*8	000030	COND	R*8	000038
CI	R*8	000040	XLMG	R*8	000048	DUM1	R*8	N.R.	DUM2	R*8	N.R.
SI	R*8	000060	OFST	R*8	N.R.	DUM3	R*8	N.R.	DUM4	R*8	N.R.
DUM5	R*8	N.R.	DOP	R*8	N.R.	DEK	R*8	0000C8	DAK	R*8	0000D0
DNK	R*8	000008	XMK	R*8	0000E0	DUM	R*8	N.R.	XS	R*8	000108
YS	R*8	000150	ZS	R*8	000198	DTK	R*8	N.R.	ELAT	R*8	N.R.
ELON	R*8	N.R.	GEOM	R*8	N.R.	HEAD	R*8	N.R.	RATE	R*8	N.R.
IDAY	I*4	N.R.	MDAY	I*4	N.R.	STIM	R*8	N.R.	DLAT	R*8	N.R.
DLON	R*8	N.R.	SMXE	R*8	N.R.	SELV	R*8	N.R.	FLAT	R*8	N.R.
FLON	R*8	N.R.	FFRQ	R*8	N.R.	RSQ	R*8	N.R.	VN	R*8	N.R.
I	I*4	N.R.	J	I*4	N.R.	K	I*4	000300	L	I*4	N.R.
M	I*4	N.R.	N	I*4	N.R.	NOOP	I*4	N.R.	ITER	I*4	N.R.
T	R*8	000318	TEMP	R*8	000320	EK	R*8	000328	AK	R*8	000330
UK	R*8	000338	VK	R*8	000340	WK	R*8	000348	CMK	R*8	000350
SWK	R*8	000358	XKP	R*8	000360	YKP	R*8	000368	BK	R*8	000370
CBK	R*8	000378	SBK	R*8	000380						

NAME OF COMMON BLOCK * COMC* SIZE OF BLOCK 000126 HEXADECIMAL BYTES

VAR. NAME	TYPE	REL. ADDR.	VAR. NAME	TYPE	REL. ADDR.	VAR. NAME	TYPE	REL. ADDR.	VAR. NAME	TYPE	REL. ADDR.
NULL	I*4	N.R.	IONE	I*4	N.R.	ITWO	I*4	N.R.	IFOR	I*4	N.R.
I15	I*4	N.R.	I30	I*4	N.R.	I365	I*4	N.R.	IN	I*4	N.R.
KM	I*4	N.R.	KF	I*4	N.R.	TAW	R*8	N.R.	WAVE	R*8	N.R.
CVCG	R*8	N.R.	EFRQ	R*8	N.R.	OMGE	R*8	000048	XOSQ	R*8	N.R.
ZOSQ	R*8	N.R.	ZERO	R*8	N.R.	ONE	R*8	N.R.	TWO	R*8	N.R.
THRE	R*8	N.R.	FOUR	R*8	N.R.	FIVE	R*8	N.R.	ATE	R*8	N.R.
TEN	R*8	N.R.	D60	R*8	N.R.	HUND	R*8	N.R.	C480	R*8	N.R.
STP5	R*8	N.R.	TOPI	R*8	N.R.	DTRA	R*8	N.R.	DTUM	R*8	N.R.
TM1	R*8	N.R.	TM4	R*8	N.R.	TM5	R*8	N.R.	TM7	R*8	N.R.
TM8	R*8	N.R.	CMIR	R*8	N.R.	CKRM	R*8	N.R.	C2K	R*8	N.R.
C2M	R*8	N.R.	REFC	R*8	N.R.						

OPTIONS IN EFFECT NAME= MAIN,OPT=02,LINECNT=56,SIZE=0000K,

OPTIONS IN EFFECT SOURCE,EBCDIC,NOLIST,NODECK,LOAD,MAP,NOEDIT,ID,NOXREF

STATISTICS SOURCE STATEMENTS = 45 ,PROGRAM SIZE = 612

STATISTICS NO DIAGNOSTICS GENERATED

****** END OF COMPILATION ****** 61K BYTES OF CORE NOT USED

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          COMPILER OPTIONS - NAME=  MAIN,OPT=02,LINECNT=58,SIZE=0000K,
                             SOURCE,EBCDIC,NOLIST,NODECK,LOAD,MAP,NOEDIT,ID,NOXREF
 ISN 0002          SUBROUTINE SOLVE                                                  SOLVE
             C                                                                       SOLVE
             C-USES SLNT WHICH CALCULATES NAVIGATOR COORDINATES AND SLANT RANGE      SOLVE
             C                                                                       SOLVE
 ISN 0003          DOUBLE PRECISION TAW,WAVE,CVCG,EFRQ,OMGE,XOSQ,ZOSQ                SOLVE
 ISN 0004          DOUBLE PRECISION ONE,TWO,THRE,FIVE,ATE,TEN,D60,HUND,C480,S7P5     SOLVE
 ISN 0005          DOUBLE PRECISION TOPI,DTRA,DFUM,TM1,TM4,TM5,TM8,CMTR,CKRM         SOLVE
 ISN 0006          DOUBLE PRECISION ZERO,FOUR,TM7,C2K,C2M,REFC                       SOLVE
 ISN 0007          DOUBLE PRECISION DOP,XS,YS,ZS,ELAT,ELON,GEOH,STIM,HEAD,RATE       SOLVE
 ISN 0008          DOUBLE PRECISION DTK ,TP,XNOT,SUME,SUMD,E,AU,COME,COMD,CI,XLMG    SOLVE
 ISN 0009          DOUBLE PRECISION DUM,DUM2,SI,OFST,DUM3,DUM4,DUM5                  SOLVE
 ISN 0010          DOUBLE PRECISION DLAT,DLON,SMXE,SELV,FLAT,FLON,FFRQ,RSQ,VN        SOLVE
 ISN 0011          DOUBLE PRECISION T  ,TEMP,A                                       SOLVE
 ISN 0012          DOUBLE PRECISION C,    B11,B12,B10,B22,B20                        SOLVE
 ISN 0013          DOUBLE PRECISION S,S2,S3                                          SOLVE
 ISN 0014          DOUBLE PRECISION XLAT,XLON,XFRQ                                   SOLVE
 ISN 0015          DOUBLE PRECISION DET                                              SOLVE
             C                                                                       SOLVE
             C---DIMENSION                                                           SOLVE
 ISN 0016          DIMENSION A(3,4)                                                  SOLVE
 ISN 0017          DIMENSION DOP(8),XS(9),YS(9),ZS(11),DLAT(9),DLON(9)               SOLVE
 ISN 0018          DIMENSION C(4)                                                    SOLVE
             C                                                                       SOLVE
             C---COMMON                                                              SOLVE
 ISN 0019          COMMON TP,XNOT,SUME,SUMD,E,AU,COME,COMD,CI,XLMG                   SOLVE
 ISN 0020          COMMON DUM, DUM2,SI,OFST,DUM3,DUM4,DUM5,DOP                       SOLVE
 ISN 0021          COMMON B11,B12,B22,B10,B20,XLAT,XLON,XFRQ                         SOLVE
 ISN 0022          COMMON XS,YS,ZS,DTK,ELAT,ELON,GEOH,HEAD,RATE,IDAY,MDAY,STIM       SOLVE
 ISN 0023          COMMON DLAT,DLON,SMXE,SELV,FLAT,FLON,FFRQ,RSQ,VN                  SOLVE
 ISN 0024          COMMON I,J,K,L,M,N,NDOP,ITER                                      SOLVE
 ISN 0025          COMMON T  ,TEMP,A                                                 SOLVE
 ISN 0026          COMMON C                                                          SOLVE
             C                                                                       SOLVE
 ISN 0027          COMMON /COMC/NULL,IONE,ITWO,IFOR,I15,I30,I365,IM,XM,KF            SOLVE
 ISN 0028          COMMON /COMC/TAW,WAVE,CVCG,EFRQ,OMGE,XOSQ,ZOSQ,ZERO               SOLVE
 ISN 0029          COMMON /COMC/ONE,TWO,THRE,FOUR,FIVE,ATE,TEN,D60,HUND              SOLVE
 ISN 0030          COMMON /COMC/C480,S7P5,TOPI,DTRA,DFUM                             SOLVE
 ISN 0031          COMMON /COMC/TM1,TM4,TM5,TM7,TM8,CMTR,CKRM,C2K,C2M,REFC           SOLVE
             C                                                                       SOLVE
 ISN 0032          EQUIVALENCE   (B11,S),(B12,S2),(B22,S3),(TEMP,DET)                SOLVE
             C                                                                       SOLVE
 ISN 0033          DO 9 ITER=1,10                                                    SOLVE
             C---INITIALIZE                                                          SOLVE
 ISN 0034          DO 1 I=1,3                                                        SOLVE
 ISN 0035          DO 1 J=1,4                                                        SOLVE
 ISN 0036        1 A(I,J)=ZERO                                                       SOLVE
 ISN 0037          SMXE=ZERO                                                         SOLVE
 ISN 0038          RSQ=ZERO                                                          SOLVE
 ISN 0039          NDOP=NULL                                                         SOLVE
 ISN 0040          K=IONE                                                            SOLVE
             C---FORM THE A MATRIX                                                   SOLVE
 ISN 0041          CALL SLNT                                                         SOLVE
 ISN 0042          C(1)=WAVE*TAW                                                     SOLVE
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 ISN 0043          DO 4 N=1,IM                                                       SOLVE
 ISN 0044          C(2)=S2                                                           SOLVE
 ISN 0045          C(3)=S3                                                           SOLVE
 ISN 0046          C(4)=S                                                            SOLVE
 ISN 0047          K=N+IONE                                                          SOLVE
 ISN 0048          CALL SLNT                                                         SOLVE
 ISN 0049          C(2)=S2-C(2)                                                      SOLVE
 ISN 0050          C(3)=S3-C(3)                                                      SOLVE
 ISN 0051          C(4)=S-C(4)                                                       SOLVE
 ISN 0052          IF (DOP(N)) 4,4,2                                                 SOLVE
 ISN 0053        2 NDOP=NDOP+IONE                                                    SOLVE
 ISN 0054          C(4)=WAVE*DOP(N)-C(1)*FFRQ-C(4)                                   SOLVE
 ISN 0055          RSQ=RSQ+C(4)*C(4)                                                 SOLVE
 ISN 0056          DO 3 I=1,3                                                        SOLVE
 ISN 0057          DO 3 J=1,4                                                        SOLVE
 ISN 0058        3 A(I,J)=A(I,J)+C(I)*C(J)                                           SOLVE
 ISN 0059        4 CONTINUE                                                          SOLVE
             C---SOLVE A MATRIX FOR DELTA LAT,LON,FREQ  BY ELIMINATING FREQUENCY     SOLVE
 ISN 0060          DET=A(1,2)/A(1,1)                                                 SOLVE
 ISN 0061          B11=A(2,2)-A(1,2)*DET                                             SOLVE
 ISN 0062          B12=A(2,3)-A(1,3)*DET                                             SOLVE
 ISN 0063          B10=A(2,4)-A(1,4)*DET                                             SOLVE
 ISN 0064          DET=A(1,3)/A(1,1)                                                 SOLVE
 ISN 0065          B22=A(3,3)-A(1,3)*DET                                             SOLVE
 ISN 0066          B20=A(3,4)-A(1,4)*DET                                             SOLVE
 ISN 0067          DET=B11*B22-B12*B12                                               SOLVE
 ISN 0068          XLAT=(B22*B10-B12*B20)/DET                                        SOLVE
 ISN 0069          XLON=(B11*B20-B12*B10)/DET                                        SOLVE
 ISN 0070          XFRQ=( A(1,4)-A(1,2)*XLAT-A(1,3)*XLON)/A(1,1)                     SOLVE
             C---UPDATE NEW ESTIMATE                                                 SOLVE
 ISN 0071          FLAT=FLAT+XLAT                                                    SOLVE
 ISN 0072          FLON=FLON+XLON                                                    SOLVE
 ISN 0073          FFRQ=FFRQ+XFRQ                                                    SOLVE
             C---CONVERGENCE CRITERIA  = .0004 NM AND  2.4 CPM                       SOLVE
 ISN 0074          D2P4=2.4D+0                                                       SOLVE
 ISN 0075          DET=CVCG/DCOS(FLAT)                                               SOLVE
 ISN 0076          IF (DABS(XLAT)-CVCG) 7,7,9                                        SOLVE
 ISN 0077        7 IF (DABS(XLON)-DET) 8,8,9                                         SOLVE
 ISN 0078        8 IF (DABS(XFRQ)-D2P4) 10,10,9                                      SOLVE
 ISN 0079        9 CONTINUE                                                          SOLVE
 ISN 0080       10 RETURN                                                            SOLVE
 ISN 0081          END                                                               SOLVE
```

NAME	TAG	TYPE	ADD.	NAME	TAG	TYPE	ADD.	NAME	TAG	TYPE	ADD.	NAME	TAG	TYPE	ADD.
A	SF C	R*8	000328	C	SF C	R*8	000388	E	C	R*8	N.R.	I	SF C	I*4	0002F8
J	SF C	I*4	0002FC	K	S C	I*4	000300	L	C	I*4	N.R.	M	C	I*4	N.R.
N	SF C	I*4	00030C	S	F CE	R*8	0000C8	T	C	R*8	N.R.	AD	C	R*8	N.R.
CI	C	R*8	N.R.	IM	F C	I*4	00001C	KF	C	I*4	N.R.	KM	C	I*4	N.R.
SI	C	R*8	N.R.	S2	F CE	R*8	000000	S3	F CE	R*8	000008	TP	C	R*8	N.R.
VN	C	R*8	N.R.	XS	C	R*8	N.R.	YS	C	R*8	N.R.	ZS	C	R*8	N.R.
ATE	C	R*8	N.R.	B10	SF C	R*8	0000E0	B11	SF CE	R*8	0000C8	B12	SF CE	R*8	0000D0
B20	SF C	R*8	0000E8	B22	SF CE	R*8	0000D8	C2K	C	R*8	N.R.	C2M	C	R*8	N.R.
DET	SF CE	R*8	000320	DOP	F C	R*8	000088	DTK	C	R*8	N.R.	D60	C	R*8	N.R.
I15	C	I*4	N.R.	I30	C	I*4	N.R.	ONE	C	R*8	N.R.	RSQ	SF C	R*8	0002E8
TAW	F C	R*8	000028	TEN	C	R*8	N.R.	TM1	C	R*8	N.R.	TM4	C	R*8	N.R.
TM5	C	R*8	N.R.	TM7	C	R*8	N.R.	TM8	C	R*8	N.R.	TWO	C	R*8	N.R.
CKRM	C	R*8	N.R.	CMTR	C	R*8	N.R.	COMD	C	R*8	N.R.	COME		R*8	N.R.
CVCG	F C	R*8	000038	C480	C	R*8	N.R.	DLAT	C	R*8	N.R.	DLON	C	R*8	N.R.
DTOM	C	R*8	N.R.	DTRA	C	R*8	N.R.	DUM1	C	R*8	N.R.	DUM2	C	R*8	N.R.
DUM3	C	R*8	N.R.	DUM4	C	R*8	N.R.	DUM5	C	R*8	N.R.	D2P4	S	R*4	000098
EFRQ	C	R*8	N.R.	ELAT	C	R*8	N.R.	ELON	C	R*8	N.R.	FFRQ	SF C	R*8	0002E0
FIVE	C	R*8	N.R.	FLAT	SFA C	R*8	000200	FLON	SF C	R*8	000208	FOUR	C	R*8	N.R.
GEOM	C	R*8	N.R.	HEAD	C	R*8	N.R.	HUND	C	R*8	N.R.	IDAY	C	I*4	N.R.
IFOR	C	I*4	N.R.	IONE	F C	I*4	000004	ITER	SF C	I*4	000314	ITWO	C	I*4	N.R.
I365	C	I*4	N.R.	MDAY	C	I*4	N.R.	NOOP	SF C	I*4	000310	NULL	F C	I*4	000000
OFST	C	R*8	N.R.	OMGE	C	R*8	N.R.	RATE	C	R*8	N.R.	REFC	C	R*8	N.R.
SELV	C	R*8	N.R.	SLNT	SF XF	R*4	000000	SMXE	S C	R*8	0002C0	SOMD	C	R*8	N.R.
SOME	C	R*8	N.R.	STIM	C	R*8	N.R.	S7P5	C	R*8	N.R.	TEMP	CE	R*8	000320
THRE	C	R*8	N.R.	TOPI	C	R*8	N.R.	WAVE	F C	R*8	000030	XFRQ	SFA C	R*8	000100
XLAT	SFA C	R*8	0000F0	XLMG	C	R*8	N.R.	XLON	SFA C	R*8	0000F8	XNDT	C	R*8	N.R.
XOSQ	C	R*8	N.R.	ZERO	F C	R*8	000060	ZOSQ	C	R*8	N.R.	SOLVE		R*4	00009C
DCOS	XF	R*8	000000												

***** COMMON INFORMATION *****

NAME OF COMMON BLOCK * * SIZE OF BLOCK 0003A8 HEXADECIMAL BYTES

VAR. NAME	TYPE	REL. ADDR.	VAR. NAME	TYPE	REL. ADDR.	VAR. NAME	TYPE	REL. ADDR.	VAR. NAME	TYPE	REL. ADDR.
TP	R*8	N.R.	XNDT	R*8	N.R.	SOME	R*8	N.R.	SOMD	R*8	N.R.
E	R*8	N.R.	AD	R*8	N.R.	COME	R*8	N.R.	COMD	R*8	N.R.
CI	R*8	N.R.	XLMG	R*8	N.R.	DUM1	R*8	N.R.	DUM2	R*8	N.R.
SI	R*8	N.R.	OFST	R*8	N.R.	DUM3	R*8	N.R.	DUM4	R*8	N.R.
DUM5	R*8	N.R.	DOP	R*8	000088	B11	R*8	0000C8	B12	R*8	0000D0
B22	R*8	0000D8	B10	R*8	0000E0	B20	R*8	0000E8	XLAT	R*8	0000F0
XLON	R*8	0000F8	XFRQ	R*8	000100	XS	R*8	N.R.	YS	R*8	N.R.
ZS	R*8	N.R.	DTK	R*8	N.R.	ELAT	R*8	N.R.	ELON	R*8	N.R.
GEOM	R*8	N.R.	HEAD	R*8	N.R.	RATE	R*8	N.R.	IDAY	I*4	N.R.
MDAY	I*4	N.R.	STIM	R*8	N.R.	DLAT	R*8	N.R.	DLON	R*8	N.R.
SMXE	R*8	0002C0	SELV	R*8	N.R.	FLAT	R*8	000200	FLON	R*8	000208
FFRQ	R*8	0002E0	RSQ	R*8	0002E8	VN	R*8	N.R.	I	I*4	0002F8
J	I*4	0002FC	K	I*4	000300	L	I*4	N.R.	M	I*4	N.R.
N	I*4	00030C	NOOP	I*4	000310	ITER	I*4	000314	T	R*8	N.R.
TEMP	R*8	000320	A	R*8	000328	C	R*8	000388			

EQUIVALENCED VARIABLES WITHIN THIS COMMON BLOCK

VARIABLE	OFFSET	VARIABLE	OFFSET	VARIABLE	OFFSET	VARIABLE	OFFSET
S	0000C8	S2	000000	S3	000008	DET	000320

NAME OF COMMON BLOCK * CONC* SIZE OF BLOCK 000128 HEXADECIMAL BYTES

VAR. NAME	TYPE	REL. ADDR.	VAR. NAME	TYPE	REL. ADDR.	VAR. NAME	TYPE	REL. ADDR.	VAR. NAME	TYPE	REL. ADDR.
NULL	I*4	000000	IONE	I*4	000004	ITWO	I*4	N.R.	IFOR	I*4	N.R.
I15	I*4	N.R.	I30	I*4	N.R.	I365	I*4	N.R.	IM	I*4	00001C
KM	I*4	N.R.	KF	I*4	N.R.	TAW	R*8	000028	WAVE	R*8	000030
CVCG	R*8	000038	EFRQ	R*8	N.R.	OMGE	R*8	N.R.	XOSQ	R*8	N.R.
ZOSQ	R*8	N.R.	ZERO	R*8	000060	ONE	R*8	N.R.	TWO	R*8	N.R.
THRE	R*8	N.R.	FOUR	R*8	N.R.	FIVE	R*8	N.R.	ATE	R*8	N.R.
TEN	R*8	N.R.	D60	R*8	N.R.	HUND	R*8	N.R.	C480	R*8	N.R.
S7P5	R*8	N.R.	TOPI	R*8	N.R.	DTRA	R*8	N.R.	DTOM	R*8	N.R.
TM1	R*8	N.R.	TM4	R*8	N.R.	TM5	R*8	N.R.	TM7	R*8	N.R.
TM8	R*8	N.R.	CMTR	R*8	N.R.	CKRM	R*8	N.R.	C2K	R*8	N.R.
C2M	R*8	N.R.	REFC	R*8	N.R.						

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LABEL   ADDR              LABEL   ADDR              LABEL   ADDR              LABEL   ADDR          PAGE 005

    1  00016E                 2  000242                 3  0002A2                 4  0002CC
    7  000426                 8  000434                 9  000442                10  000454

*OPTIONS IN EFFECT*     NAME=  MAIN,OPT=02,LINECNT=58,SIZE=0000K,

*OPTIONS IN EFFECT*     SOURCE,EBCDIC,NOLIST,NODECK,LOAD,MAP,NOEDIT,ID,NOXREF

*STATISTICS*     SOURCE STATEMENTS =      90 ,PROGRAM SIZE =     1144

*STATISTICS*  NO  DIAGNOSTICS GENERATED

****** END OF COMPILATION ******                                      53K BYTES OF CORE NOT USED
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        COMPILER OPTIONS - NAME= MAIN,OPT=02,LINECNT=58,SIZE=0000K,
                           SOURCE,EBCDIC,NOLIST,NODECK,LOAD,MAP,NOEDIT,ID,NOXREF
ISN 0002            SUBROUTINE SLNT                                              SLNT
              C                                                                  SLNT
              C---COMPUTE SLANT RANGE AND DERIVATIVES FOR POINT K AND ELEVATION  SLNT
              C                                                                  SLNT
ISN 0003            DOUBLE PRECISION TAW,WAVE,CVCG,EFRQ,OMGE,XOSQ,ZOSQ           SLNT
ISN 0004            DOUBLE PRECISION ONE,TWO,THRE,FIVE,ATE,TEN,D60,HUND,C480,S7P5 SLNT
ISN 0005            DOUBLE PRECISION TOPI,DTRA,DTOM,TM1,TM4,TM5,TM8,CMTR,CKRM    SLNT
ISN 0006            DOUBLE PRECISION ZERO,FOUR,TM7,C2K,C2M,REFC                  SLNT
ISN 0007            DOUBLE PRECISION DOP,XS,YS,ZS,ELAT,ELON,GEOH,STIM,HEAD,RATE  SLNT
ISN 0008            DOUBLE PRECISION DTK,TP,XNDT,SUME,SUMD,E,AO,CUME,CUMD,CI,XLMG SLNT
ISN 0009            DOUBLE PRECISION DUM1,DUM2,SI,OFST,DUM3,DUM4,DUM5            SLNT
ISN 0010            DOUBLE PRECISION DLAT,DLON,SMXE,SELV,FLAT,FLON,FFRQ,RSQ,VN   SLNT
ISN 0011            DOUBLE PRECISION T,TEMP                                      SLNT
ISN 0012            DOUBLE PRECISION A                                           SLNT
ISN 0013            DOUBLE PRECISION XN,YN,ZN,XN2,YN2,ZN2,X,Y,Z                  SLNT
ISN 0014            DOUBLE PRECISION CLAT,SLAT,SLON,CLON,D,C                     SLNT
ISN 0015            DOUBLE PRECISION S,S2,S3                                     SLNT
              C                                                                  SLNT
              C---DIMENSIONS                                                     SLNT
ISN 0016            DIMENSION DOP(8),XS(9),YS(9),ZS(11),DLAT(9),DLON(9)          SLNT
ISN 0017            DIMENSION A(3,4),C(4)                                        SLNT
              C                                                                  SLNT
              C---COMMON                                                         SLNT
ISN 0018            COMMON TP,XNDT,SUME,SUMD,E,AO,CUME,CUMD,CI,XLMG              SLNT
ISN 0019            COMMON DUM1,DUM2,SI,OFST,DUM3,DUM4,DUM5,DOP                  SLNT
ISN 0020            COMMON CLAT,SLAT,SLON,CLON,D,XN,YN,ZN                        SLNT
ISN 0021            COMMON XS,YS,ZS,DTK,ELAT,ELON,GEOH,HEAD,RATE,IDAY,MDAY,STIM  SLNT
ISN 0022            COMMON DLAT,DLON,SMXE,SELV,FLAT,FLON,FFRQ,RSQ,VN             SLNT
ISN 0023            COMMON I,J,K,L,M,N,NDOP,ITER                                 SLNT
ISN 0024            COMMON T,TEMP,A                                              SLNT
ISN 0025            COMMON C,X,Y,Z,XN2,YN2,ZN2                                   SLNT
              C                                                                  SLNT
ISN 0026            COMMON /COMC/NULL,IONE,ITWO,IFOR,I15,I30,I365,IM,KM,KF       SLNT
ISN 0027            COMMON /COMC/TAW,WAVE,CVCG,EFRQ,OMGE,XOSQ,ZOSQ,ZERO          SLNT
ISN 0028            COMMON /COMC/ONE,TWO,THRE,FOUR,FIVE,ATE,TEN,D60,HUND         SLNT
ISN 0029            COMMON /COMC/C480,S7P5,TOPI,DTRA,DTOM                        SLNT
ISN 0030            COMMON /COMC/TM1,TM4,TM5,TM7,TM8,CMTR,CKRM,C2K,C2M,REFC      SLNT
              C                                                                  SLNT
ISN 0031            EQUIVALENCE (CLAT,S),(SLAT,S2),(SLON,S3)                     SLNT
              C                                                                  SLNT
              C                                                                  SLNT
              C---NAVIGATORS COORDINATES AND DERIVATIVES                         SLNT
ISN 0032            TEMP=FLAT+DLAT(K)                                            SLNT
ISN 0033            CLAT=DCOS(TEMP)                                              SLNT
ISN 0034            SLAT=DSIN(TEMP)                                              SLNT
ISN 0035            TEMP=FLON+DLON(K)/CLAT                                       SLNT
ISN 0036            CLON=DCOS(TEMP)                                              SLNT
ISN 0037            SLON=DSIN(TEMP)                                              SLNT
ISN 0038            D=XOSQ*CLAT*CLAT+ZOSQ*SLAT*SLAT                              SLNT
ISN 0039            D=DSQRT(D)                                                   SLNT
ISN 0040            TEMP=XOSQ/D+GEOH                                             SLNT
ISN 0041            XN=TEMP*CLAT                                                 SLNT
ISN 0042            YN=XN*SLON                                                   SLNT
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ISN 0043            XN=XN*CLON                                                   SLNT
ISN 0044            ZN=(ZOSQ/D+GEOH)*SLAT                                        SLNT
ISN 0045            XN2=-TEMP*SLAT                                               SLNT
ISN 0046            YN2=XN2*SLON                                                 SLNT
ISN 0047            XN2=XN2*CLON                                                 SLNT
ISN 0048            ZN2=TEMP*CLAT                                                SLNT
              C---SLANT RANGE AND DERIVATIVES                                    SLNT
ISN 0049            X=XS(K)-XN                                                   SLNT
ISN 0050            Y=YS(K)-YN                                                   SLNT
ISN 0051            Z=ZS(K)-ZN                                                   SLNT
ISN 0052            S2=X*X+Y*Y+Z*Z                                               SLNT
ISN 0053            S=DSQRT(S2)                                                  SLNT
ISN 0054            S2=-(X*XN2+Y*YN2+Z*ZN2)/S                                    SLNT
ISN 0055            S3=(X*YN-Y*XN)/S                                             SLNT
              C---COMPUTE SIN(ELEV) AND SAVE MAXIMUM                             SLNT
ISN 0056            SELV= (X*XN+Y*YN+Z*ZN)/(S*D)                                 SLNT
ISN 0057            IF (SELV-SMXE) 2,2,1                                         SLNT
ISN 0058          1 SMXE=SELV                                                    SLNT
ISN 0059          2 RETURN                                                       SLNT
ISN 0060            END                                                          SLNT
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/ SLNT / SIZE OF PROGRAM 0002EE HEXADECIMAL BYTES PAGE 003

NAME	TAG	TYPE	ADD.
A	C	R*8	N.R.
I	C	I*4	N.R.
N	C	I*4	N.R.
X	SF C	R*8	0003A8
CI	C	R*4	N.R.
SI	C	R*8	N.R.
VN	C	R*8	N.R.
YS	F C	R*8	000150
C2K	C	R*8	N.R.
D60	C	R*8	N.R.
RSQ	C	R*8	N.R.
TM4	C	R*8	N.R.
TWO	C	R*8	N.R.
CKRN	C	R*8	N.R.
COMD	C	R*8	N.R.
DLAT	F C	R*8	000230
DUM1	C	R*8	N.R.
DUM5	C	R*8	N.R.
FFRQ	C	R*8	N.R.
FOUR	C	R*8	N.R.
IDAY	C	I*4	N.R.
ITWO	C	I*4	N.R.
NULL	C	I*4	N.R.
REFC	C	R*8	N.R.
SLON	SF CE	R*8	000008
STIH	C	R*8	N.R.
TOPI	C	R*8	N.R.
XOSQ	F C	R*8	000050
OSIN	XF	R*8	000000

NAME	TAG	TYPE	ADD.
C	C	R*8	N.R.
J	C	I*4	N.R.
N	C	I*4	N.R.
Y	SF C	R*8	000380
IM	C	I*4	N.R.
S2	SFA CE	R*8	000000
XN	SF C	R*8	0000F0
ZN	SF C	R*8	000100
C2M	C	R*8	N.R.
I15	C	I*4	N.R.
TAW	C	R*8	N.R.
TM5	C	R*8	N.R.
XN2	SF C	R*8	0003C0
CLAT	SF CE	R*8	0000C8
COME	C	R*8	N.R.
DLON	F C	R*8	000278
DUM2	C	R*8	N.R.
EFRQ	C	R*8	N.R.
FIVE	C	R*8	N.R.
GEOH	F C	R*8	000208
IFOR	C	I*4	N.R.
I365	C	I*4	N.R.
OFST	C	R*8	N.R.
SELV	SF C	R*8	0002C8
SMXE	S C	R*8	0002C0
S7P5	C	R*8	N.R.
WAVE	C	R*8	N.R.
ZERO	C	R*8	N.R.
DCOS	XF	R*8	000000

NAME	TAG	TYPE	ADD.
D	SFA C	R*8	0000E8
K	F C	I*4	000300
S	SF CE	R*8	0000C8
Z	SF C	R*8	000388
KF	C	I*4	N.R.
S3	S CE	R*8	0000D8
XS	F C	R*8	000108
ZS	F C	R*8	000198
DOP	C	R*8	N.R.
I30	C	I*4	N.R.
TEN	C	R*8	N.R.
TM7	C	R*8	N.R.
YN2	SF C	R*8	0003C8
CLON	SF C	R*8	0000E0
CVCG	C	R*8	N.R.
DTOM	C	R*8	N.R.
DUM3	C	R*8	N.R.
ELAT	C	R*8	N.R.
FLAT	F C	R*8	000200
HEAD	C	R*8	N.R.
IONE	C	I*4	N.R.
MDAY	C	I*4	N.R.
UMGE	C	R*8	N.R.
SLAT	SF CE	R*8	000000
SOMD	C	R*8	N.R.
TEMP	SFA C	R*8	000320
XLMG	C	R*8	N.R.
ZOSQ	F C	R*8	000058

NAME	TAG	TYPE	ADD.
E	C	R*8	N.R.
L	C	I*4	N.R.
T	C	R*8	N.R.
AD	C	R*8	N.R.
KM	C	I*4	N.R.
TP	C	R*8	N.R.
YN	SF C	R*8	0000F8
ATE	C	R*8	N.R.
OTK	C	R*8	N.R.
UNE	C	R*8	N.R.
TM1	C	R*8	N.R.
TM8	C	R*8	N.R.
ZN2	SF C	R*8	0003D0
CMTR	C	R*8	N.R.
C480	C	R*8	N.R.
DTRA	C	R*8	N.R.
DUM4	C	R*8	N.R.
ELON	C	R*8	N.R.
FLON	F C	R*8	000208
HUND	C	R*8	N.R.
ITER	C	I*4	N.R.
NDOP	C	I*4	N.R.
RATE	C	R*8	N.R.
SLNT		R*4	000094
SOME	C	R*8	N.R.
THRE	C	R*8	N.R.
XNDT	C	R*8	N.R.
DSQRT	XF	R*8	000000

***** COMMUN INFORMATION *****

NAME OF COMMON BLOCK * * SIZE UF BLOCK 000308 HEXADECIMAL BYTES

VAR. NAME	TYPE	REL. ADDR.
TP	R*8	N.R.
E	R*8	N.R.
CI	R*8	N.R.
SI	R*8	N.R.
DUM5	R*8	N.R.
SLON	R*8	000008
YN	R*8	0000F8
ZS	R*8	000198
GEOH	R*8	000208
MDAY	I*4	N.R.
SMXE	R*8	0002C0
FFRQ	R*8	N.R.
J	I*4	N.R.
N	I*4	N.R.
TEMP	R*8	000320
Y	R*8	000380
ZN2	R*8	000300

VAR. NAME	TYPE	REL. ADDR.
XNDT	R*8	N.R.
AD	R*8	N.R.
XLMG	R*8	N.R.
OFST	R*8	N.R.
DOP	R*8	N.R.
CLON	R*8	0000E0
ZN	R*8	000100
DTK	R*8	N.R.
HEAD	R*8	N.R.
STIM	R*8	N.R.
SELV	R*8	0002C8
RSQ	R*8	N.R.
K	I*4	000300
NDOP	I*4	N.R.
A	R*8	N.R.
Z	R*8	000388

VAR. NAME	TYPE	REL. ADDR.
SOME	R*8	N.R.
COME	R*8	N.R.
DUM1	R*8	N.R.
DUM3	R*8	N.R.
CLAT	R*8	0000C8
D	R*8	0000E8
XS	R*8	000108
ELAT	R*8	N.R.
RATE	R*8	N.R.
DLAT	R*8	000230
FLAT	R*8	000200
VN	R*8	N.R.
L	I*4	N.R.
ITER	I*4	N.R.
C	R*8	N.R.
XN2	R*8	0003C0

VAR. NAME	TYPE	REL. ADDR.
SOMD	R*8	N.R.
COMD	R*8	N.R.
DUM2	R*8	N.R.
DUM4	R*8	N.R.
SLAT	R*8	000000
XN	R*8	0000F0
YS	R*8	000150
ELON	R*8	N.R.
IDAY	I*4	N.R.
DLON	R*8	000278
FLON	R*8	000208
I	I*4	N.R.
M	I*4	N.R.
T	R*8	N.R.
X	R*8	0003A8
YN2	R*8	0003C8

EQUIVALENCED VARIABLES WITHIN THIS COMMON BLOCK

VARIABLE	OFFSET	VARIABLE	OFFSET	VARIABLE	OFFSET	VARIABLE	OFFSET
S	0000C8	S2	0000D0	S3	0000D8		

NAME OF COMMON BLOCK * COMC* SIZE OF BLOCK 000128 HEXADECIMAL BYTES

VAR. NAME	TYPE	REL. ADDR.	VAR. NAME	TYPE	REL. ADDR.	VAR. NAME	TYPE	REL. ADDR.	VAR. NAME	TYPE	REL. ADDR.
NULL	I*4	N.R.	IONE	I*4	N.R.	ITWO	I*4	N.R.	IFOR	I*4	N.R.
I15	I*4	N.R.	I30	I*4	N.R.	I365	I*4	N.R.	IM	I*4	N.R.
KM	I*4	N.R.	KF	I*4	N.R.	TAW	R*8	N.R.	WAVE	R*8	N.R.
CVCG	R*8	N.R.	EFRQ	R*8	N.R.	OMGE	R*8	N.R.	XOSQ	R*8	000050
ZOSQ	R*8	000058	ZERO	R*8	N.R.	ONE	R*8	N.R.	TWO	R*8	N.R.
THRE	R*8	N.R.	FOUR	R*8	N.R.	FIVE	R*8	N.R.	ATE	R*8	N.R.
TEN	R*8	N.R.	D60	R*8	N.R.	HUND	R*8	N.R.	C480	R*8	N.R.
S7P5	R*8	N.R.	TOPI	R*8	N.R.	DTRA	R*8	N.R.	DTOM	R*8	N.R.
TM1	R*8	N.R.	TM4	R*8	N.R.	TM5	R*8	N.R.	TM7	R*8	N.R.
TM8	R*8	N.R.	CMTR	R*8	N.R.	CKRM	R*8	N.R.	C2K	R*8	N.R.
C2M	R*8	N.R.	REFC	R*8	N.R.						

```
  LABEL    ADDR              LABEL    ADDR              LABEL    ADDR              LABEL    ADDR          PAGE 005
      1  0002?2                  2  0002CA
*OPTIONS IN EFFECT*     NAME=  MAIN,OPT=02,LINECNT=58,SIZE=0000K,
*OPTIONS IN EFFECT*     SOURCE,EBCDIC,NOLIST,NODECK,LOAD,MAP,NOEDIT,ID,NOXREF
*STATISTICS*     SOURCE STATEMENTS =      59 ,PROGRAM SIZE =      750
*STATISTICS*  NO  DIAGNOSTICS GENERATED
****** END OF COMPILATION ******                                   61? BYTES OF CORE NOT USED
```

```
        COMPILER OPTIONS - NAME=  MAIN,OPT=02,LINECNT=58,SIZE=0000K,
                          SOURCE,EBCDIC,NOLIST,NODECK,LOAD,MAP,NOEDIT,ID,NOXREF
ISN 0002            SUBROUTINE EDIT                                                 EDIT
              C                                                                     EDIT
              C-USES SLNT                                                           EDIT
              C---THROW OUT DOPPLERS BELOW 7.5 DEG AS LONG AS 4 DOPPLER REMAIN      EDIT
              C                                                                     EDIT
ISN 0003            DOUBLE PRECISION TAW,WAVE,CVCG,EFRQ,OMGE,XOSQ,ZOSQ              EDIT
ISN 0004            DOUBLE PRECISION ONE,TWO,THRE,FIVF,ATE,TEN,D60,HUND,C480,S7P5   EDIT
ISN 0005            DOUBLE PRECISION TOPI,DTRA,DTOM,TM1,TM4,TM5,TM8,CMTR,CKRM       EDIT
ISN 0006            DOUBLE PRECISION ZERO,FOUR,TM7,C2K,C2M,REFC                     EDIT
ISN 0007            DOUBLE PRECISION DOP,REF,XS,YS,ZS,ELAT,ELON,GEOH,STIM,HEAD,RATE EDIT
ISN 0008            DOUBLE PRECISION DTK,TP,XNDT,SOME,SOMD,E,AD,COME,COMD,CI,XLMG   EDIT
ISN 0009            DOUBLE PRECISION DUM1,DUM2,SI,OFST,DUM3,DUM4,DUM5               EDIT
ISN 0010            DOUBLE PRECISION DLAT,DLON,SMXE,SELV,FLAT,FLON,FFRQ,RSQ,VN      EDIT
ISN 0011            DOUBLE PRECISION T,TEMP                                         EDIT
ISN 0012            DOUBLE PRECISION EE,EB                                          EDIT
              C                                                                     EDIT
              C---DIMENSIONS                                                        EDIT
ISN 0013            DIMENSION DOP(8),REF(8),XS(9),YS(9),ZS(11),DLAT(9),DLON(9)      EDIT
              C                                                                     EDIT
              C---COMMON                                                            EDIT
ISN 0014            COMMON TP,XNDT,SOME,SOMD,E,AD,COME,COMD,CI,XLMG                 EDIT
ISN 0015            COMMON DUM1,DUM2,SI,OFST DUM3,DUM4,DUM5,DOP                     EDIT
ISN 0016            COMMON REF                                                      EDIT
ISN 0017            COMMON XS,YS,ZS,DTK,ELAT,ELON,GEOH,HEAD,RATE,IDAY,MDAY,STIM     EDIT
ISN 0018            COMMON DLAT,DLON,SMXE,SELV,FLAT,FLON,FFRQ,RSQ,VN                EDIT
ISN 0019            COMMON I,J,K,L,M,N,NDOP,ITER                                    EDIT
ISN 0020            COMMON T,TEMP,EE,EB                                             EDIT
              C                                                                     EDIT
ISN 0021            COMMON /COMC/NULL,IONE,ITWO,IFOR I15,I30,I365,IM,KM,KF          EDIT
ISN 0022            COMMON /COMC/TAW,WAVE,CVCG,EFRQ,OMGE,XOSQ,ZOSQ,ZERO             EDIT
ISN 0023            COMMON /COMC/ONE,TWO,THRE,FOUR,FIVF,ATE,TEN,D60,HUND            EDIT
ISN 0024            COMMON /COMC/C480,S7P5,TOPI,DTRA,DTOM                           EDIT
ISN 0025            COMMON /COMC/TM1,TM4,TM5,TM7,TM8,CMTR,CKRM,C2K,C2M,REFC         EDIT
              C                                                                     EDIT
ISN 0026            I=IONE                                                          EDIT
ISN 0027            J=KM                                                            EDIT
ISN 0028          1 IF (NDOP-IFOR)11,11,2                                           EDIT
ISN 0029          2 K=I                                                             EDIT
ISN 0030            CALL SLNT                                                       EDIT
ISN 0031            EB=SELV                                                         EDIT
ISN 0032            K=J                                                             EDIT
ISN 0033            CALL SLNT                                                       EDIT
ISN 0034            EE=SELV                                                         EDIT
ISN 0035            IF (EE-S7P5) 4,4,5                                              EDIT
ISN 0036          4 IF (EE-EB) 7,7,5                                                EDIT
ISN 0037          5 IF (EB-S7P5) 6,6,11                                             EDIT
ISN 0038          6 L=I                                                             EDIT
ISN 0039            I=I+IONE                                                        EDIT
ISN 0040            GO TO 8                                                         EDIT
ISN 0041          7 L=J-IONE                                                        EDIT
ISN 0042            J=L                                                             EDIT
ISN 0043          8 IF (DOP(L)) 9,10,9                                              EDIT
ISN 0044          9 DOP(L)=ZERO                                                     EDIT
```



```
ISN 0045            NDOP=NDOP-IONE                                                  EDIT
ISN 0046         10 GO TO 1                                                         EDIT
ISN 0047         11 RETURN                                                          EDIT
ISN 0048            END                                                             EDIT
```

/ EDIT / SIZE OF PROGRAM 000192 HEXADECIMAL BYTES PAGE 003

NAME	TAG	TYPE	ADD.	NAME	TAG	TYPE	ADD.	NAME	TAG	TYPE	ADD.	NAME	TAG	TYPE	ADD.
E	C	R*8	N.R.	I SF	C	I*4	0002F8	J SF	C	I*4	0002FC	K S	C	I*4	000300
L SF	C	I*4	000304	M	C	I*4	N.R.	N	C	I*4	N.R.	T	C	R*8	N.R.
AD	C	R*8	N.R.	CI	C	R*8	N.R.	EB S	C	R*8	000330	EE S	C	R*8	000328
IM	C	I*4	N.R.	XF	C	I*4	N.R.	KM F	C	I*4	000020	SI	C	R*8	N.R.
TP	C	R*8	N.R.	VN	C	R*8	N.R.	XS	C	R*8	N.R.	YS	C	R*8	N.R.
ZS	C	R*8	N.R.	ATE	C	R*8	N.R.	C2K	C	R*8	N.R.	C2M	C	R*8	N.R.
DOP S	C	R*8	000088	DTK	C	R*8	N.R.	D60	C	R*8	N.R.	I15	C	I*4	N.R.
I30	C	I*4	N.R.	ONE	C	R*8	N.R.	REF	C	R*8	N.R.	RSQ	C	R*8	N.R.
[illegible]	C	R*8	N.R.	TEN	C	R*8	N.R.	TM1	C	R*8	N.R.	TM4	C	R*8	N.R.
TM5	C	R*8	N.R.	TM7	C	R*8	N.R.	TM8	C	R*8	N.R.	TWO	C	R*8	N.R.
CKRM	C	R*8	N.R.	CMTR	C	R*8	N.R.	COMD	C	R*8	N.R.	COME	C	R*8	N.R.
CVCG	C	R*8	N.R.	C480	C	R*8	N.R.	DLAT	C	R*8	N.R.	DLON	C	R*8	N.R.
DTOM	C	R*8	N.R.	DTPA	C	R*8	N.R.	DUM1	C	R*8	N.R.	DUM2	C	R*8	N.R.
DUM3	C	R*8	N.R.	DUM4	C	R*8	N.R.	DUM5	C	R*8	N.R.	EDIT		R*4	000078
EFRQ	C	R*8	N.R.	ELAT	C	R*8	N.R.	ELON	C	R*8	N.R.	FFRQ	C	R*8	N.R.
FIVE	C	R*8	N.R.	FLAT	C	R*8	N.R.	FLON	C	R*8	N.R.	FOUR	C	R*8	N.R.
GEOH	C	R*8	N.R.	HEAD	C	R*8	N.R.	HUND	C	R*8	N.R.	IDAY	C	I*4	N.R.
IFOR	C	I*4	00000C	IONE F	C	I*4	000004	ITER	C	I*4	N.R.	ITWO	C	I*4	N.R.
I365	C	I*4	N.R.	MDAY	C	I*4	N.R.	NOOP SF	C	I*4	000310	NULL	C	I*4	N.R.
OFST	C	R*8	N.R.	OMGE	C	R*8	N.R.	RATE	C	R*8	N.R.	REFC	C	R*8	N.R.
SELV F	C	R*8	0002C8	SLNT SF	XF	R*4	000000	SMXE	C	R*8	N.R.	SOMD	C	R*8	N.R.
SOME	C	R*8	N.R.	STIM	C	R*8	N.R.	STPS	C	R*8	000088	TEMP	C	R*8	N.R.
THRE	C	R*8	N.R.	TOPI	C	R*8	N.R.	WAVE	C	R*8	N.R.	XLMG	C	R*8	N.R.
XNDT	C	R*8	N.R.	XOSQ	C	R*8	N.R.	ZERO F	C	R*8	000060	ZOSQ	C	R*8	N.R.

***** COMMON INFORMATION *****

NAME OF COMMON.BLOCK * * SIZE OF BLOCK 000338 HEXADECIMAL BYTES

VAR. NAME	TYPE	REL. ADDR.	VAR. NAME	TYPE	REL. ADDR.	VAR. NAME	TYPE	REL. ADDR.	VAR. NAME	TYPE	REL. ADDR.
TP	R*8	N.R.	XNDT	R*8	N.R.	SOME	R*8	N.R.	SOMD	R*8	N.R.
E	R*8	N.R.	AD	R*8	N.R.	COME	R*8	N.R.	COMD	R*8	N.R.
CI	R*8	N.R.	XLMG	R*8	N.R.	DUM1	R*8	N.R.	DUM2	R*8	N.R.
SI	R*8	N.R.	OFST	R*8	N.R.	DUM3	R*8	N.R.	DUM4	R*8	N.R.
DUM5	R*8	N.R.	DOP	R*8	000088	REF	R*8	N.R.	XS	R*8	N.R.
YS	R*8	N.R.	ZS	R*8	N.R.	DTK	R*8	N.R.	ELAT	R*8	N.R.
ELON	R*8	N.R.	GEOH	R*8	N.R.	HEAD	R*8	N.R.	RATE	R*8	N.R.
IDAY	I*4	N.R.	MDAY	I*4	N.R.	STIM	R*8	N.R.	DLAT	R*8	N.R.
DLON	R*8	N.R.	SMXE	R*8	N.R.	SELV	R*8	0002C8	FLAT	R*8	N.R.
FLON	R*8	N.R.	FFRQ	R*8	N.R.	RSQ	R*8	N.R.	VN	R*8	N.R.
I	I*4	0002F8	J	I*4	0002FC	K	I*4	000300	L	I*4	000304
M	I*4	N.R.	N	I*4	N.R.	NOOP	I*4	000310	ITER	I*4	N.R.
T	R*8	N.R.	TEMP	R*8	N.R.	EE	R*8	000328	EB	R*8	000330

NAME OF COMMON BLOCK * COMC* SIZE OF BLOCK 000128 HEXADECIMAL BYTES

VAR. NAME	TYPE	REL. ADDR.	VAR. NAME	TYPE	REL. ADDR.	VAR. NAME	TYPE	REL. ADDR.	VAR. NAME	TYPE	REL. ADDR.
NULL	I*4	N.R.	IONE	I*4	000004	ITWO	I*4	N.R.	IFOR	I*4	00000C
I15	I*4	N.R.	I30	I*4	N.R.	I365	I*4	N.R.	IM	I*4	N.R.
KM	I*4	000020	XF	I*4	N.R.	TAW	R*8	N.R.	WAVE	R*8	N.R.
CVCG	R*8	N.R.	EFRQ	R*8	N.R.	OMGE	R*8	N.R.	XOSQ	R*8	N.R.

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ZOSQ	R*8	N.R.	ZERO	R*8	000060	ONE	R*8	N.R.	TWO	R*8	N.R.
THRE	R*8	N.R.	FOUR	R*8	N.R.	FIVE	R*8	N.R.	ATE	R*8	N.R.
TEN	R*8	N.R.	D60	R*8	N.R.	HUND	R*8	N.R.	C480	R*8	N.R.
STPS	R*8	000088	TOPI	R*8	N.R.	DTRA	R*8	N.R.	DTOM	R*8	N.R.
TM1	R*8	N.R.	TM4	R*8	N.R.	TM5	R*8	N.R.	TM7	R*8	N.R.
TM8	R*8	N.R.	CMTR	R*8	N.R.	CKRM	R*8	N.R.	C2K	R*8	N.R.
C2M	R*8	N.R.	REFC	R*8	N.R.						

```
 LABEL   ADDR              LABEL   ADDR              LABEL   ADDR              LABEL   ADDR            PAGE 005

     1  0000A8                 2  0000B8                 4  0000F8                 5  000104
     6  000114                 7  00012C                 8  000140                 9  000152
    10  00016A                11  00016E

*OPTIONS IN EFFECT*     NAME= MAIN,OPT=02,LINECNT=58,SIZE=0000K,

*OPTIONS IN EFFECT*     SOURCE,EBCDIC,NOLIST,NODECK,LOAD,MAP,NOEDIT,ID,NOXREF

*STATISTICS*    SOURCE STATEMENTS   =     47 ,PROGRAM SIZE =      402

*STATISTICS*  NO  DIAGNOSTICS GENERATED

****** END OF COMPILATION ******                                         61K BYTES OF CORE NOT USED
```

```
          COMPILER OPTIONS - NAME=  MAIN,OPT=02,LINECNT=58,SIZE=0000K,
                             SOURCE,EBCDIC,NOLIST,NODECK,LOAD,MAP,NOEDIT,ID,NOXREF
  ISN 0002            SUBROUTINE ALRT                                             ALRT
                C                                                                 ALRT
                C-USES AVIS WHICH USES SLNT AND SXYZ                              ALRT
                C                                                                 ALRT
  ISN 0003            DOUBLE PRECISION TAW,WAVE,CVCG,EFRQ,OMCE,XOSQ,ZOSQ          ALRT
  ISN 0004            DOUBLE PRECISION ONE,TWO,THRE,FIVE,ATE,TEN,D60,HUND,C480,S7P5 ALRT
  ISN 0005            DOUBLE PRECISION TOPI,DTRA,DTOM,TM1,TM4,TM5,TM8,CMTR,CKRM   ALRT
  ISN 0006            DOUBLE PRECISION ZERO,FOUR,TM7,C2K,C2M,REFC                 ALRT
  ISN 0007            DOUBLE PRECISION DOP,XS,YS,ZS,ELAT,ELON,GEOH,STIM,HEAD,RATE ALRT
  ISN 0008            DOUBLE PRECISION DTK,TP,XNDT,SOME,SOMD,E,AO,COME,COMD,CI,XLMG ALRT
  ISN 0009            DOUBLE PRECISION DUM1,DUM2,SI,OFST,DUM3,DUM4,DUM5           ALRT
  ISN 0010            DOUBLE PRECISION DLAT,DLON,SMXE,SELV,FLAT,FLON,FFRQ,RSQ,VN  ALRT
  ISN 0011            DOUBLE PRECISION T,TEMP,A                                   ALRT
  ISN 0012            DOUBLE PRECISION DEK,DAK,DNK                                ALRT
  ISN 0013            DOUBLE PRECISION DUM                                        ALRT
  ISN 0014            DOUBLE PRECISION AELV                                       ALRT
  ISN 0015            DOUBLE PRECISION TO  ,RISE,XMIN                             ALRT
                C                                                                 ALRT
                C---DIMENSIONS                                                    ALRT
  ISN 0016            DIMENSION DOP(8),XS(9),YS(9),ZS(11),DLAT(9),DLON(9)         ALRT
  ISN 0017            DIMENSION DUM(5),A(3,4)                                     ALRT
                C                                                                 ALRT
                C---COMMON                                                        ALRT
  ISN 0018            COMMON TP,XNDT,SOME,SOMD,F,AO,COME,COMD,CI,XLMG             ALRT
  ISN 0019            COMMON DUM1,DUM2,SI,OFST,DUM3,DUM4,DUM5,DOP                 ALRT
  ISN 0020            COMMON DEK,DAK,DNK,DUM                                      ALRT
  ISN 0021            COMMON XS,YS,ZS,DTK,ELAT,ELON,GEOH,HEAD,RATE,IDAY,MDAY,STIM ALRT
  ISN 0022            COMMON DLAT,DLON,SMXE,SELV,FLAT,FLON,FFRQ,RSQ,VN            ALRT
  ISN 0023            COMMON I,J,K,L,M,N,NDOP,ITER                                ALRT
  ISN 0024            COMMON T,TEMP,A                                             ALRT
  ISN 0025            COMMON TO  ,RISE,AELV,XMIN                                  ALRT
                C                                                                 ALRT
  ISN 0026            COMMON /CONC/NULL,IONE,ITWO,IFOR,I15,I30,I[illegible],IM,KM,KF     ALRT
  ISN 0027            COMMON /CONC/TAW,WAVE,CVCG,EFRQ,OMGE,XOSQ,  [illegible]Q,ZERO   ALRT
  ISN 0028            COMMON /CONC/ONE,TWO,THRE,FOUR,FIVE,ATE,TEN,D60,HUND        ALRT
  ISN 0029            COMMON /CONC/C480,S7P5,TOPI,DTRA,DTOM                       ALRT
  ISN 0030            COMMON /CONC/TM1,TM4,TM5,TM7,TM8,CMTR,CKRM,C2K,C2M,REFC     ALRT
                C                                                                 ALRT
  ISN 0031            EQUIVALENCE (ISTP,NDOP),(IELV,ITER)                         ALRT
  ISN 0032          1 FORMAT (1H1,3HDAY,3X,4HRISE,3X,4HELEV)                      ALRT
  ISN 0033            ISTP=MDAY-IDAY                                              ALRT
  ISN 0034            IF (ISTP) 2,13,3                                            ALRT
  ISN 0035          2 ISTP=ISTP+I365                                              ALRT
  ISN 0036          3 TO=T-18.0D0                                                 ALRT
  ISN 0037            T=TO-TEN                                                    ALRT
  ISN 0038            WRITE (6,1)                                                 ALRT
  ISN 0039          4 T=T+TEN                                                     ALRT
  ISN 0040            CALL AVIS                                                   ALRT
  ISN 0041            IF (SELV) 4,4,5                                             ALRT
  ISN 0042          5 T=T-TEN                                                     ALRT
  ISN 0043          6 T=T+TWO                                                     ALRT
  ISN 0044            CALL AVIS                                                   ALRT
  ISN 0045            IF (SELV) 6,7,7                                             ALRT
```



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  ISN 0046          7 RISE=STIM+T-TO                                              ALRT
  ISN 0047          8 AELV=SELV                                                   ALRT
  ISN 0048            T=T+2.5D-1                                                  ALRT
  ISN 0049            CALL AVIS                                                   ALRT
  ISN 0050            IF (SELV-AELV) 9,8,8                                        ALRT
  ISN 0051          9 CALL ARCS (AELV)                                            ALRT
  ISN 0052            IELV=AELV                                                   ALRT
  ISN 0053            I=RISE/DTOM                                                 ALRT
  ISN 0054            K=I+IDAY                                                    ALRT
  ISN 0055            IF (K-I365) 11,11,10                                        ALRT
  ISN 0056         10 K=K-I365                                                    ALRT
  ISN 0057         11 TEMP=I                                                      ALRT
  ISN 0058            RISE=RISE-DTOM*TEMP                                         ALRT
  ISN 0059            TEMP=RISE*CMTR                                              ALRT
  ISN 0060            CALL UCON                                                   ALRT
  ISN 0061            WRITE (6,12) K,L,M,IELV                                     ALRT
  ISN 0062         12 FORMAT (1H,I3,3X,2I2,4X,I2)                                 ALRT
  ISN 0063            IF (I-ISTP) 4,4,13                                          ALRT
  ISN 0064         13 RETURN                                                      ALRT
  ISN 0065            END                                                         ALRT
```

/ ALRT / SIZE OF PROGRAM 000310 HEXADECIMAL BYTES PAGE 003

NAME	TAG	TYPE	ADD.	NAME	TAG	TYPE	ADD.	NAME	TAG	TYPE	ADD.	NAME	TAG	TYPE	ADD.
A	C	R*8	N.R.	E	C	R*8	N.R.	I	SF C	I*	0002F8	J	C	I*4	N.R.
K	SF C	I*4	000300	L	F C	I*4	000304	M	F C	I*4	000308	N	C	I*4	N.R.
T	SF C	R*8	000318	AO	C	R*8	N.R.	CI	C	R*8	N.R.	IM	C	I*4	N.R.
KF	C	I*4	N.R.	KM	C	I*4	N.R.	SI	C	R*8	N.R.	TO	SF C	R*8	000388
TP	C	R*8	N.R.	VN	C	R*8	N.R.	XS	C	R*8	N.R.	YS	C	R*8	N.R.
ZS	C	R*8	N.R.	ATE	C	R*8	N.R.	C2K	C	R*8	N.R.	C2M	C	R*8	N.R.
DAK	C	R*8	N.R.	DEK	C	R*8	N.R.	DNK	C	R*8	N.R.	DOP	C	R*8	N.R.
DTK	C	R*8	N.R.	DUM	C	R*8	N.R.	D60	C	R*8	N.R.	I15	C	I*4	N.R.
I33	C	I*4	N.R.	UNE	C	R*8	N.R.	RSQ	C	R*8	N.R.	TAW	C	R*8	N.R.
TEN	F C	R*8	000098	TM1	C	R*8	N.R.	TM4	C	R*8	N.R.	TM5	C	R*8	N.R.
TM7	C	R*8	N.R.	TM8	C	R*8	N.R.	TWO	F C	R*8	000070	AELV	SFA C	R*8	000398
ALRT		R*4	0000CC	ARCS	SF XF	R*4	000000	AVIS	SF XF	R*4	000000	CKRM	C	R*8	N.R.
CMTR	F C	R*8	000100	COMD	C	R*8	N.R.	COME	C	R*8	N.R.	CVCG	C	R*8	N.R.
C480	C	R*8	N.R.	DLAT	C	R*8	N.R.	DLON	C	R*8	N.R.	DTOM	F C	R*8	000000
CTRA	C	R*8	N.R.	DUM1	C	R*8	N.R.	DUM2	C	R*8	N.R.	DUM3	C	R*8	N.R.
DUM4	C	R*8	N.R.	DUM5	C	R*8	N.R.	EFRQ	C	R*8	N.R.	ELAT	C	R*8	N.R.
ELON	C	R*8	N.R.	FFRQ	C	R*8	N.R.	FIVE	C	R*8	N.R.	FLAT	C	R*8	N.R.
FLON	C	R*8	N.R.	FOUR	C	R*8	N.R.	GEOH	C	R*8	N.R.	HEAD	C	R*8	N.R.
HUND	C	R*8	N.R.	IDAY	F C	I*4	000220	IELV	SF CE	I*4	000314	IFOR	C	I*4	N.R.
IONE	C	I*4	N.R.	ISTP	SF CE	I*4	000310	ITER	CE	I*4	000314	ITWO	C	I*4	N.R.
I365	F C	I*4	000018	MDAY	F C	I*4	000224	NOOP	CE	I*4	000310	NULL	C	I*4	N.R.
OFST	C	R*8	N.R.	OMGE	C	R*8	N.R.	RATE	C	R*8	N.R.	REFC	C	R*8	N.R.
RISE	SF C	R*8	000390	SELV	F C	R*8	0002C8	SMXE	C	R*8	N.R.	SOMD	C	R*8	N.R.
SOME	C	R*8	N.R.	STIM	F C	R*8	000228	S7P5	C	R*8	N.R.	TEMP	SF C	R*8	000320
THRE	C	R*8	N.R.	TOPI	C	R*8	N.R.	UCON	SF XF	R*4	000000	WAVE	C	R*8	N.R.
XLMG	C	R*8	N.R.	XMIN	C	R*8	N.R.	XNOT	C	R*8	N.R.	XOSQ	C	R*8	N.R.
ZERO	C	R*8	N.R.	ZOSD	C	R*8	N.R.	IBCOM	F XF	R*4	000000				

***** COMMON INFORMATION *****

NAME OF COMMON BLOCK * * SIZE OF BLOCK 0003A8 HEXADECIMAL BYTES

VAR. NAME	TYPE	REL. ADDR.	VAR. NAME	TYPE	REL. ADDR.	VAR. NAME	TYPE	REL. ADDR.	VAR. NAME	TYPE	REL. ADDR.
TP	R*8	N.R.	XNOT	R*8	N.R.	SOME	R*8	N.R.	SOMD	R*8	N.R.
E	R*8	N.R.	AO	R*8	N.R.	COME	R*8	N.R.	COMD	R*8	N.R.
CI	R*8	N.R.	XLMG	R*8	N.R.	DUM1	R*8	N.R.	DUM2	R*8	N.R.
SI	R*8	N.R.	OFST	R*8	N.R.	DUM3	R*8	N.R.	DUM4	R*8	N.R.
DUM5	R*8	N.R.	DOP	R*8	N.R.	DEK	R*8	N.R.	DAK	R*8	N.R.
DNK	R*8	N.R.	DUM	R*8	N.R.	XS	R*8	N.R.	YS	R*8	N.R.
ZS	R*8	N.R.	DTK	R*8	N.R.	ELAT	R*8	N.R.	ELON	R*8	N.R.
GEOH	R*8	N.R.	HEAD	R*8	N.R.	RATE	R*8	N.R.	IDAY	I*4	000220
MDAY	I*4	000224	STIM	R*8	000228	DLAT	R*8	N.R.	DLON	R*8	N.R.
SMXE	R*8	N.R.	SELV	R*8	0002C8	FLAT	R*8	N.R.	FLON	R*8	N.R.
EFRQ	R*8	N.R.	RSQ	R*8	N.R.	VN	R*8	N.R.	I	I*4	0002F8
J	I*4	N.R.	K	I*4	000300	L	I*4	000304	M	I*4	000308
N	I*4	N.R.	NOOP	I*4	000310	ITER	I*4	000314	T	R*8	000318
TEMP	R*8	000320	A	R*8	N.R.	TO	R*8	000388	RISE	R*8	000390
AELV	R*8	000398	XMIN	R*8	N.R.						

EQUIVALENCED VARIABLES WITHIN THIS COMMON BLOCK

VARIABLE	OFFSET	VARIABLE	OFFSET	VARIABLE	OFFSET	VARIABLE	OFFSET
ISTP	000310	IELV	000314				

NAME OF COMMON BLOCK * COMC* SIZE OF BLOCK 000126 HEXADECIMAL BYTES

VAR. NAME	TYPE	REL. ADDR.	VAR. NAME	TYPE	REL. ADDR.	VAR. NAME	TYPE	REL. ADDR.	VAR. NAME	TYPE	REL. ADDR.
NULL	I*4	N.R.	IONE	I*4	N.R.	ITWO	I*4	N.R.	IFOR	I*4	N.R.
I15	I*4	N.R.	I30	I*4	N.R.	I365	I*4	000018	IM	I*4	N.R.
KM	I*4	N.R.	KF	I*4	N.R.	TAW	R*8	N.R.	WAVE	R*8	N.R.
CVCG	R*8	N.R.	EFRQ	R*8	N.R.	OMGE	R*8	N.R.	XOSQ	R*8	N.R.
ZOSQ	R*8	N.R.	ZERO	R*8	N.R.	ONE	R*8	N.R.	TWO	R*8	000070
THREE	R*8	N.R.	FOUR	R*8	N.R.	FIVE	R*8	N.R.	ATE	R*8	N.R.
TEN	R*8	000098	DEG	R*8	N.R.	HUND	R*8	N.R.	C480	R*8	N.R.
STPS	R*8	N.R.	TOPI	R*8	N.R.	DTRA	R*8	N.R.	DTOM	R*8	0000D0
TM1	R*8	N.R.	TM4	R*8	N.R.	TM5	R*8	N.R.	TM7	R*8	N.R.
TM8	R*8	N.R.	CMTR	R*8	0001C0	CKRM	R*8	N.R.	C2K	R*8	N.R.
C2M	R*8	N.R.	PEFC	R*8	N.R.						

```
LABEL   ADDR            LABEL   ADDR            LABEL   ADDR            LABEL   ADDR          PAGE 0 ?

    2  000110              3  000120               4  00014C               5  000170
    6  000180              7  0001AC               8  00018C               9  0001EE
   10  000254             11  000258              13  0002EC

*OPTIONS IN EFFECT*    NAME=  MAIN,OPT=02,LINECNT=58,SIZE=0000K,

*OPTIONS IN EFFECT*    SOURCE,EBCDIC,NOLIST,NODECK,LOAD,MAP,NOEDIT-10,NOXREF

*STATISTICS*    SOURCE STATEMENTS =     64 ,PROGRAM SIZE =      784

*STATISTICS*  NO  DIAGNOSTICS GENERATED

****** END OF COMPILATION ******                                  61K BYTES OF CORE NOT USED
```

```
0001        SUBROUTINE AVIS                                                    AVIS
      C                                                                        AVIS
      C                                                                        AVIS
0002        DOUBLE PRECISION TAN,WAVE,CVCG,[illegible],XOSQ,ZOSQ               AVIS
0003        DOUBLE PRECISION ONE,TWO,THRE,F[illegible],TEN,D60,HUND,C480,S7P5  AVIS
0004        DOUBLE PRECISION TOPI,DTRA,[illegible],TM7,TM8,CMTR,CKRM           AVIS
0005        DOUBLE PRECISION ZERO,FOUR,TM7,C2K,C2M,PERC                        AVIS
0006        DOUBLE PRECISION DOP,[illegible],XS,YS,ZS,ELAT,ELON,GEOH,STIM,HEAD,RATE AVIS
0007        DOUBLE PRECISION DAT,TP,XNOT,SOPE,SOMD,L,XO,COME,COMD,CI,ALMG      AVIS
0008        DOUBLE PRECISION DUM1,DUM2,SI,OFST,DUM3,DUM4,DUM5                  AVIS
0009        DOUBLE PRECISION DLAT,DLON,SMAL,SELV,FLAT,F[illegible]N,FFRQ,RSQ,VA AVIS
0010        DOUBLE PRECISION T,TEMP,A                                          AVIS
0011        DOUBLE PRECISION TO                                                AVIS
0012        DOUBLE PRECISION DGR,DAR,DNR                                       AVIS
      C                                                                        AVIS
      C---DIMENSIONS                                                           AVIS
0013        DIMENSION DOP(8),[illegible],XS(9),YS(9),ZS(11),ELAT(9),ELON(9)    AVIS
0014        DIMENSION A(3,4)                                                   AVIS
      C                                                                        AVIS
      C---COMMON                                                               AVIS
0015        COMMON TP,XNOT,SOPE,SOMD,S,XO,COME,COMD,CI,ALMG                    AVIS
0016        COMMON DUM1,DUM2,SI,OFST,DUM3,DUM4,DUM5,DOP                        AVIS
0017        COMMON DGR,DAR,DNR,DOR                                             AVIS
0018        COMMON XS,YS,ZS,DTR,ELAT,ELON,GEOH,HEAD,RATE,IDAY,FDAY,STIM        AVIS
0019        COMMON DLAT,DLON,SMAL,SELV,FLAT,FLON,FFRQ,RSQ,VA                   AVIS
0020        COMMON I,J,K,L,M,N,NDOP,ITER                                       AVIS
0021        COMMON T,TEMP,A                                                    AVIS
0022        COMMON TO                                                          AVIS
      C                                                                        AVIS
0023        COMMON /COMC/NULL,IONE,ITWO,IFOR,I15,I30,I365,IN,KN,KF             AVIS
0024        COMMON /COMC/TAN,WAVE,CVCG,FFRQ,OMGE,XOSQ,ZOSQ,ZERO                AVIS
0025        COMMON /COMC/ONE,TWO,THRE,FOUR,FIVE,ATE,TEN,D60,HUND               AVIS
0026        COMMON /COMC/C480,S7P5,TOPI,DTRA,DTOR                              AVIS
0027        COMMON /COMC/TM1,TM4,TM5,TM7,TM8,CMTR,CKRM,C2K,C2M,PERC            AVIS
      C                                                                        AVIS
      C-USES SLNT AND SAYZ TO GET SINE OF ELEVATION ANGLE                      AVIS
0028        N=IONE                                                             AVIS
0029        DGR=ZERO                                                           AVIS
0030        DAR=ZERO                                                           AVIS
0031        DNR=ZERO                                                           AVIS
0032        CALL SAYZ                                                          AVIS
0033        CALL SLNT                                                          AVIS
0034        RETURN                                                             AVIS
0035        END                                                                AVIS
                                                                               AVIS
```

COMMON BLOCK / / MAP SIZE 390

SYMBOL	LOCATION	SYMBOL	LOCATION	SYMBOL	LOCATION	SYMBOL	LOCATION	SYMBOL	LOCATION
TP	0	XNOT	8	SOME	10	SOMD	18	E	20
AO	28	COME	30	COMD	38	CI	40	XLNG	48
DUM1	50	DUM2	58	SI	60	OFST	68	DUM3	70
DUM4	78	DUM5	80	DOP	88	DEK	C8	DAK	D0
DNK	D8	DUM	E0	XS	108	YS	150	ZS	158
DTK	1F0	ELAT	1F8	ELON	200	GEOM	208	HEAD	210
RATE	218	IDAY	220	MDAY	224	STIM	228	SLAT	230
DLON	278	SMXE	2C0	SELV	2C8	FLAT	2D0	FLON	2D8
FFRQ	2E0	MSQ	2E8	VN	2F0	I	2F8	J	2FC
K	300	L	304	N	308	N	30C	NDOP	310
ITER	314	T	318	TEMP	320	A	328	TO	388

COMMON BLOCK /COMC / MAP SIZE 128

SYMBOL	LOCATION	SYMBOL	LOCATION	SYMBOL	LOCATION	SYMBOL	LOCATION	SYMBOL	LOCATION
NULL	0	IONE	4	ITWO	8	IFOR	C	I15	10
I30	14	[illegible]	18	IN	1C	RE	20	C2	24
C4	28	WAVE	30	CVCG	38	EFRQ	40	OMGE	48
ZONE	50	ZCSQ	58	ZERO	60	ONE	68	TWO	70
THRE	78	FOUR	80	FIVE	88	ATE	90	[illegible]	98
[illegible]	AC	HUND	A8	C480	B0	S7P5	B8	TOPI	C0
[illegible]	C8	LTOM	D0	TM1	D8	TP4	E0	TM5	E8
[illegible]	FC	TM8	F8	CNTR	100	CKEE	108	C2K	110
C2M	118	REFC	120						

SUBPROGRAMS CALLED

SYMBOL	LOCATION	SYMBOL	LOCATION	SYMBOL	LOCATION	SYMBOL	LOCATION	SYMBOL	LOCATION
SATZ	98	SLAT	9C						

```
*OPTIONS IN EFFECT* ID,EBCDIC,SOURCE,NOLIST,NODECK,LOAD,MAP
*OPTIONS IN EFFECT* NAME = AVIS , LINECNT = 58
*STATISTICS* SOURCE STATEMENTS = 55,PROGRAM SIZE = 322
*STATISTICS* NO DIAGNOSTICS GENERATED
```

```
LEVEL 18 ( SEPT 69 )                    OS/360  FORTRAN H                                    DATE  70.196/18.54.52

        COMPILER OPTIONS - NAME=  MAIN,OPT=02,LINECNT=58,SIZE=0000K,
                           SOURCE,EBCDIC,NOLIST,NODECK,LOAD,MAP,NOEDIT,ID,NOXREF
  ISN 0002            SUBROUTINE ARCS (ARG)                                                   ARCS
  ISN 0003            DOUBLE PRECISION ARG,X                                                  ARCS
  ISN 0004            X=.5D+0                                                                 ARCS
                C--THE ACCURACY IS DEPENDENT UPON THE NUMBER OF ITERATIONS                    ARCS
  ISN 0005            DO 1 I=1,6                                                              ARCS
  ISN 0006          1 X=X+(ARG-DSIN(X))/DCOS(X)                                               ARCS
  ISN 0007            ARG=X*.572957795131D+2                                                  ARCS
  ISN 0008            RETURN                                                                  ARCS
  ISN 0009            END                                                                     ARCS
```

```
                              /     ARCS /     SIZE OF PROGRAM 000166 HEXADECIMAL BYTES PAGE 002

NAME    TAG  TYPE  ADD.      NAME    TAG  TYPE  ADD.      NAME    TAG  TYPE  ADD.      NAME    TAG  TYPE  ADD.
   I SF      I*4   000098        X SFA    R*8   0000A0     ARG SF      R*8   0000A8     ARCS         R*4   00009C
 DCOS    XF  R*8   000000     DSIN    XF  R*8   000000
```

```
 LABEL   ADDR              LABEL   ADDR              LABEL   ADDR              LABEL   ADDR          PAGE 003
    1  0000DC
*OPTIONS IN EFFECT*     NAME=  MAIN,OPT=02,LINECNT=58,SIZE=0000K,
*OPTIONS IN EFFECT*     SOURCE,EBCDIC,NOLIST,NODECK,LOAD,MAP,NOEDIT,ID,NOXREF
*STATISTICS*     SOURCE STATEMENTS =       8 ,PROGRAM SIZE =       358
*STATISTICS*  NO  DIAGNOSTICS GENERATED
****** END OF COMPILATION ******                                  65K BYTES OF CORE NOT USED
```

```
        COMPILER OPTIONS - NAME=  MAIN,OPT=02,LINECNT=58,SIZE=0000K,
                           SOURCE,EBCDIC,NOLIST,NODECK,LOAD,MAP,NOEDIT,ID,NOXREF
  ISN 0002            SUBROUTINE TYPE                                              TYPE
                C                                                                  TYPE
  ISN 0003            DOUBLE PRECISION TAW,WAVE,CVCG,EFRQ,OMGE,XOSQ,ZOSQ            TYPE
  ISN 0004            DOUBLE PRECISION ONE,TWO,THRE,FIVE,ATE,TEN,D60,HUND,C480,S7P5 TYPE
  ISN 0005            DOUBLE PRECISION TOPI,DTRA,DTOM,TM1,TM4,TM5,TM8,CMTR,CKRM     TYPE
  ISN 0006            DOUBLE PRECISION ZERO,FOUR,TM7,C2K,C2M,REFC                   TYPE
  ISN 0007            DOUBLE PRECISION DOP,REF,XS,YS,ZS,ELAT,ELON,GEOH,STIM,HEAD,RATE TYPE
  ISN 0008            DOUBLE PRECISION DTK,TP,XNDT,SOME,SOMD,E,AO,COME,COMD,CI,XLMG TYPE
  ISN 0009            DOUBLE PRECISION DUM1,DUM2,SI,OFST,DUM3,DUM4,DUM5             TYPE
  ISN 0010            DOUBLE PRECISION DLAT,DLON,SMXE,SELV,FLAT,FLON,FFRQ,RSQ,VN    TYPE
  ISN 0011            DOUBLE PRECISION T,TEMP,A                                     TYPE
                C                                                                  TYPE
  ISN 0012            DOUBLE PRECISION EDOT,A1,A2,A3,A4,A5                          TYPE
  ISN 0013            DOUBLE PRECISION TEMP1,TEMP2,TEMP3,S2LAT                      TYPE
  ISN 0014            DOUBLE PRECISION V,W,DLATS,DLONS,C4P8                         TYPE
  ISN 0015            DOUBLE PRECISION TEMP4,TEMP5                                  TYPE
                C                                                                  TYPE
                C                                                                  TYPE
                C---DIMENSION                                                      TYPE
  ISN 0016            DIMENSION A(3,4)                                              TYPE
  ISN 0017            DIMENSION DOP(8),REF(8),XS(9),YS(9),ZS(11),DLAT(9),DLON(9)    TYPE
                C                                                                  TYPE
                C---COMMON                                                         TYPE
  ISN 0018            COMMON TP,XNDT,SOME,SOMD,E,AO,COME,COMD,CI,XLMG               TYPE
  ISN 0019            COMMON DUM1,DUM2,SI,OFST,DUM3,DUM4,DUM5,DOP                   TYPE
  ISN 0020            COMMON REF                                                    TYPE
  ISN 0021            COMMON XS,YS,ZS,DTK,ELAT,ELON,GEOH,HEAD,RATE,IDAY,MDAY,STIM   TYPE
  ISN 0022            COMMON DLAT,DLON,SMXE,SELV,FLAT,FLON,FFRQ,RSQ,VN              TYPE
  ISN 0023            COMMON I,J,K,L,M,N,NDOP,ITER                                  TYPE
  ISN 0024            COMMON T,TEMP,A                                               TYPE
                C                                                                  TYPE
  ISN 0025            COMMON /COMC/NULL,IONE,ITWO,IFOR,I15,I30,I365,IM,KM,KF        TYPE
  ISN 0026            COMMON /COMC/TAW,WAVE,CVCG,EFRQ,OMGE,XOSQ,ZOSQ,ZERO           TYPE
  ISN 0027            COMMON /COMC/ONE,TWO,THRE,FOUR,FIVE,ATE,TEN,D60,HUND          TYPE
  ISN 0028            COMMON /COMC/C480,S7P5,TOPI,DTRA,DTOM                         TYPE
  ISN 0029            COMMON /COMC/TM1,TM4,TM5,TM7,TM8,CMTR,CKRM,C2K,C2M,REFC       TYPE
                C                                                                  TYPE
  ISN 0030            EQUIVALENCE (A(1,1),EDOT )                                    TYPE
  ISN 0031            EQUIVALENCE (A(1,3),TEMP1),(A(1,4),TEMP2)                     TYPE
  ISN 0032            EQUIVALENCE (A(2,1),TEMP3),(A(2,2),S2LAT)                     TYPE
  ISN 0033            EQUIVALENCE (A(2,3),V    ),(A(2,4),W    )                     TYPE
  ISN 0034            EQUIVALENCE (A(3,1),DLATS),(A(3,2),DLONS)                     TYPE
  ISN 0035            EQUIVALENCE (A(3,3),TEMP4),(A(3,4),TEMP5)                     TYPE
                C                                                                  TYPE
  ISN 0036            I=0                                                           TYPE
  ISN 0037         19 TEMP4=((FFRQ-EFRQ)/D60)*HUND                                  TYPE
  ISN 0038            TEMP5=EFRQ/2.4D+4                                             TYPE
  ISN 0039            WRITE(8,110) TEMP4,TEMP5                                      TYPE
  ISN 0040        110 FORMAT(F7.1,F9.5)                                             TYPE
  ISN 0041            TEMP=SMXE                                                     TYPE
  ISN 0042            CALL ARCS(TEMP)                                               TYPE
  ISN 00              WRITE(8,111) TEMP                                             TYPE
  ISN 0044        111 FORMAT(F5.1)                                                  TYPE
```



```
  ISN 0045            TEMP=(STIM+FOUR)*CMTR                                         TYPE
  ISN 0046            CALL UCON                                                     TYPE
  ISN 0047            WRITE(8,112) L,M                                              TYPE
  ISN 0048        112 FORMAT(I2,I2)                                                 TYPE
  ISN 0049            WRITE(8,113) NDOP                                             TYPE
  ISN 0050        113 FORMAT(I2)                                                    TYPE
  ISN 0051            WRITE(8,113) ITER                                             TYPE
  ISN 0052        190 TEMP=((FLAT-ELAT)/DTRA)*D60                                   TYPE
  ISN 0053            TEMP1=(((FLON-ELON)*DCOS(FLAT))/DTRA)*D60                     TYPE
  ISN 0054            TEMP3=FLAT/DTRA                                               TYPE
  ISN 0055            J=TEMP3                                                       TYPE
  ISN 0056            TEMP3=DABS((TEMP3-DBLE(FLOAT(J)))*D60)                        TYPE
  ISN 0057            TEMP4=FLON/DTRA                                               TYPE
  ISN 0058            K=TEMP4                                                       TYPE
  ISN 0059            TEMP4=DABS((TEMP4-DBLE(FLOAT(K)))*D60)                        TYPE
  ISN 0060            WRITE(8,114) J,TEMP3,TEMP,K,TEMP4,TEMP1                       TYPE
  ISN 0061        114 FORMAT (I4,F7.4,F8.4,I4,F7.4,F8.4)                            TYPE
  ISN 0062            IF (I) 103,102,102                                            TYPE
  ISN 0063        102 EDOT=0.67393780D-02                                           TYPE
  ISN 0064            A1=-0.93137062D+0                                             TYPE
  ISN 0065            A2=0.21343908D+01                                             TYPE
  ISN 0066            A3=0.13582489D+01                                             TYPE
  ISN 0067            A4=0.11599867D-02                                             TYPE
  ISN 0068            A5=-0.34166622D+0                                             TYPE
  ISN 0069            TEMP =DSIN(FLAT)                                              TYPE
  ISN 0070            TEMP1=DCOS(FLAT)                                              TYPE
  ISN 0071            TEMP2=DSIN(FLON)                                              TYPE
  ISN 0072            TEMP3=DCOS(FLON)                                              TYPE
  ISN 0073            S2LAT=TEMP*TEMP                                               TYPE
  ISN 0074            V=ONE+EDOT*(ONE-THRE*S2LAT/TWO)                               TYPE
  ISN 0075            W=ONE-(EDOT*S2LAT/TWO)                                        TYPE
  ISN 0076            DLATS=((A1*TEMP3+A2*TEMP2)*TEMP+A3*TEMP1)*V                   TYPE
             1              +(A4*S2LAT+A5)*TEMP*TEMP1                               TYPE
  ISN 0077            DLONS=(A1*TEMP2-A2*TEMP3)*W/TEMP1                             TYPE
  ISN 0078            C4P8=4.84813681D-06                                           TYPE
  ISN 0079            FLAT=FLAT+C4P8*DLATS                                          TYPE
  ISN 0080            FLON=FLON+C4P8*DLONS                                          TYPE
  ISN 0081            I=-1                                                          TYPE
  ISN 0082            GO TO 190                                                     TYPE
  ISN 0083        103 RETURN                                                        TYPE
  ISN 0084            END                                                           TYPE
```

/ TYPE / SIZE OF PROGRAM 000550 HEXADECIMAL BYTES PAGE 003

NAME	TAG	TYPE	ADD.	NAME	TAG	TYPE	ADD.	NAME	TAG	TYPE	ADD.	NAME	TAG	TYPE	ADD.
A	CE	R*8	000328	E	C	R*8	N.R.	I	S C	I*4	0002F8	J	SFA C	I*4	0002FC
K	SFA C	I*4	000300	L	F C	I*4	000304	M	F C	I*4	000308	N	C	I*4	N.R.
T	C	R*8	N.R.	V	SF CE	R*8	000360	W	SF CE	R*8	000378	AO	C	R*8	N.R.
A1	SF	R*8	000120	A2	SF	R*8	000128	A3	SF	R*8	000130	A4	SF	R*8	000138
A5	SF	R*8	000140	CI	C	R*8	N.R.	IM	C	I*4	N.R.	KF	C	I*4	N.R.
KM	C	I*4	N.R.	SI	C	R*8	N.R.	TP	C	R*8	N.R.	VN	C	R*8	N.R.
XS	C	R*8	N.R.	YS	C	R*8	N.R.	ZS	C	R*8	N.R.	ATE	C	R*8	N.R.
C2K	C	R*8	N.R.	C2M	C	R*8	N.R.	DOP	C	R*8	N.R.	DTK	C	R*8	N.R.
D60	FA C	R*8	0000A0	I15	C	I*4	N.R.	I30	C	I*4	N.R.	ONE	F C	R*8	000068
REF	C	R*8	N.R.	RSQ	C	R*8	N.R.	TAW	C	R*8	N.R.	TEN	C	R*8	N.R.
TM1	C	R*8	N.R.	TM4	C	R*8	N.R.	TM5	C	R*8	N.R.	TM7	C	R*8	N.R.
TM8	C	R*8	N.R.	TWO	F C	R*8	000070	ARCS	SF XF	R*4	000000	CKRM	C	R*8	N.R.
CMTR	F C	R*8	000100	COMD	C	R*8	N.R.	COME	C	R*8	N.R.	CVCG	C	R*8	N.R.
C4P8	SF	R*8	000148	C480	C	R*8	N.R.	DLAT	C	R*8	N.R.	DLON	C	R*8	N.R.
DTOM	C	R*8	N.R.	DTRA	F C	R*8	0000C8	DUM1	C	R*8	N.R.	DUM2	C	R*8	N.R.
DUM3	C	R*8	N.R.	DUM4	C	R*8	N.R.	DUM5	C	R*8	N.R.	EDOT	SF CE	R*8	000328
EFRQ	F C	R*8	000040	ELAT	F C	R*8	0001F8	ELON	F C	R*8	0002C0	FFRQ	F C	R*8	0002E0
FIVE	C	R*8	N.R.	FLAT	SFA C	R*8	000200	FLON	SFA C	R*8	000208	FOUR	F C	R*8	000080
GEOM	C	R*8	N.R.	HEAD	C	R*8	N.R.	HUND	F C	R*8	0000A8	IDAY	C	I*4	N.R.
IFOR	C	I*4	N.R.	IONE	C	I*4	N.R.	ITER	F C	I*4	000314	ITWO	C	I*4	N.R.
I365	C	I*4	N.R.	MDAY	C	I*4	N.R.	NDOP	F C	I*4	000310	NULL	C	I*4	N.R.
OFST	C	R*8	N.R.	OMGE	C	R*8	N.R.	RATE	C	R*8	N.R.	REFC	C	R*8	N.R.
SELV	C	R*8	N.R.	SMXE	F C	R*8	0002C0	SOMD	C	R*8	N.R.	SOME	C	R*8	N.R.
STIM	F C	R*8	000228	S7P5	C	R*8	N.R.	TEMP	SFA C	R*8	000320	THRE	F C	R*8	000078
TOPI	C	R*8	N.R.	TYPE		R*4	00011C	UCON	SF XF	R*4	000000	WAVE	C	R*8	N.R.
XLMG	C	R*8	N.R.	XNOT	C	R*8	N.R.	XOSQ	C	R*8	N.R.	ZERO	C	R*8	N.R.
ZOSQ	C	R*8	N.R.	DLATS	SF CE	R*8	000338	DLONS	SF CE	R*8	000350	S2LAT	SF CE	R*8	000348
TEMP1	SF CE	R*8	000358	TEMP2	SF CE	R*8	000370	TEMP3	SFA CE	R*8	000330	TEMP4	SFA CE	R*8	000368
TEMP5	SF CE	R*8	000380	DSIN	XF	R*8	000000	DCOS	XF	R*8	000000	IBCOM#	F XF	R*8	000000

***** COMMON INFORMATION *****

NAME OF COMMON BLOCK * * SIZE OF BLOCK 000388 HEXADECIMAL BYTES

VAR. NAME	TYPE	REL. ADDR.	VAR. NAME	TYPE	REL. ADDR.	VAR. NAME	TYPE	REL. ADDR.	VAR. NAME	TYPE	REL. ADDR.
TP	R*8	N.R.	XNOT	R*8	N.R.	SOME	R*8	N.R.	SOMD	R*8	N.R.
E	R*8	N.R.	AO	R*8	N.R.	COME	R*8	N.R.	COMD	R*8	N.R.
CI	R*8	N.R.	XLMG	R*8	N.R.	DUM1	R*8	N.R.	DUM2	R*8	N.R.
SI	R*8	N.R.	OFST	R*8	N.R.	DUM3	R*8	N.R.	DUM4	R*8	N.R.
DUM5	R*8	N.R.	DOP	R*8	N.R.	REF	R*8	N.R.	XS	R*8	N.R.
YS	R*8	N.R.	ZS	R*8	N.R.	DTK	R*8	N.R.	ELAT	R*8	0001F8
ELON	R*8	000200	GEOM	R*8	N.R.	HEAD	R*8	N.R.	RATE	R*8	N.R.
IDAY	I*4	N.R.	MDAY	I*4	N.R.	STIM	R*8	000228	DLAT	R*8	N.R.
DLON	R*8	N.R.	SMXE	R*8	0002C0	SELV	R*8	N.R.	FLAT	R*8	0002D0
FLON	R*8	000208	FFRQ	R*8	0002E0	RSQ	R*8	N.R.	VN	R*8	N.R.
I	I*4	0002F8	J	I*4	0002FC	K	I*4	000300	L	I*4	000304
M	I*4	000308	N	I*4	N.R.	NDOP	I*4	000310	ITER	I*4	000314
T	R*8	N.R.	TEMP	R*8	000320	A	R*8	000328			

EQUIVALENCED VARIABLES WITHIN THIS COMMON BLOCK

VARIABLE	OFFSET	VARIABLE	OFFSET	VARIABLE	OFFSET	VARIABLE	OFFSET
EDOT	000328	TEMP1	000358	TEMP2	000370	TEMP3	000330

PAGE 004

S2LAT	000348	V	000360	W	000378	DLATS	000338
DLONS	000350	TEMP4	000368	TEMP5	000380		

NAME OF COMMON BLOCK * CONC* SIZE OF BLOCK 000128 HEXADECIMAL BYTES

VAR. NAME	TYPE	REL. ADDR.	VAR. NAME	TYPE	REL. ADDR.	VAR. NAME	TYPE	REL. ADDR.	VAR. NAME	TYPE	REL. ADDR.
NULL	I*4	N.R.	IONE	I*4	N.R.	ITWO	I*4	N.R.	IFOR	I*4	N.R.
I15	I*4	N.R.	I30	I*4	N.R.	I365	I*4	N.R.	IM	I*4	N.R.
KM	I*4	N.R.	KF	I*4	N.R.	TAW	R*8	N.R.	WAVE	R*8	N.R.
CVCG	R*8	N.R.	EFRQ	R*8	000040	OMGE	R*8	N.R.	XOSQ	R*8	N.R.
ZOSQ	R*8	N.R.	ZERO	R*8	N.R.	ONE	R*8	000068	TWO	R*8	000070
THRE	R*8	000078	FOUR	R*8	000080	FIVE	R*8	N.R.	ATE	R*8	N.R.
TEN	R*8	N.R.	D60	R*8	0000A0	HUND	R*8	0000A8	C480	R*8	N.R.
S7P5	R*8	N.R.	TOPI	R*8	N.R.	DTRA	R*8	0000C8	DTOM	R*8	N.R.
TM1	R*8	N.R.	TM4	R*8	N.R.	TM5	R*8	N.R.	TM7	R*8	N.R.
TM8	R*8	N.R.	CMTR	R*8	000100	CKRM	R*8	N.R.	C2K	R*8	N.R.
C2M	R*8	N.R.	REFC	R*8	N.R.						

```
  LABEL   ADDR          LABEL   ADDR          LABEL   ADDR          LABEL   ADDR          PAGE 0C5
     19  000180 NR         190  0002BA           102  0004IE           103  00052C
*OPTIONS IN EFFECT*     NAME= MAIN,OPT=02,LINECNT=58,SIZE=0000K,
```

```
*OPTIONS IN EFFECT*     SOURCE,EBCDIC,NOLIST,NODECK,LOAD,MAP,NOEDIT,ID,NOXREF
*STATISTICS*     SOURCE STATEMENTS =      83 ,PROGRAM SIZE =     1360
*STATISTICS*  NO  DIAGNOSTICS GENERATED
****** END OF COMPILATION ******                                   57K BYTES OF CORE NOT USED
```

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LEVEL 18 ( SEPT 69 )                    OS/360  FORTRAN H                                    DATE  70.196/18.54.59

          COMPILER OPTIONS - NAME=  MAIN,OPT=02,LINECNT=58,SIZE=0000K,
                             SOURCE,EBCDIC,NOLIST,NODECK,LOAD,MAP,NOEDIT,ID,NOXREF
  ISN 0002            SUBROUTINE UCON
               C                                                                  UCON
               C                                                                  UCON
  ISN 0003            DOUBLE PRECISION TAW,WAVE,CVCG,EFRQ,OMGE,XOSQ,ZOSQ          UCON
  ISN 0004            DOUBLE PRECISION ONE,TWO,THRE,FIVE,ATE,TEN,D60,HUND,C480,S7P5 UCON
  ISN 0005            DOUBLE PRECISION TUPI,DTRA,DTOM,TM1,TM4,TM5,TM8,CMTR,CKRM   UCON
  ISN 0006            DOUBLE PRECISION ZERO,FOUR,TM7,C2K,C2M,REFC                 UCON
  ISN 0007            DOUBLE PRECISION DOP,REF,DE,DA,DN,ELAT,ELON,GEOH,ETIM,HEAD,RATE UCON
  ISN 0008            DOUBLE PRECISION DTK,TP,XNDT,SOME,SOMD,E,AO,COME,COMD,CI,XLMG UCON
  ISN 0009            DOUBLE PRECISION DUM1,DUM2,SI,OFST,DUM3,DUM4,DUM5           UCON
  ISN 0010            DOUBLE PRECISION DLAT,DLON,SMXE,SELV,FLAT,FLON,FFRQ,RSQ,VN  UCON
  ISN 0011            DOUBLE PRECISION T,TEMP,A,DUM                               UCON
  ISN 0012            DOUBLE PRECISION Y,Z                                        UCON
               C                                                                  UCON
               C---DIMENSIONS                                                     UCON
  ISN 0013            DIMENSION DOP(8),REF(8),DE(9),DA(9),DN(11),DLAT(9),DLON(9)  UCON
  ISN 0014            DIMENSION A(3,4),DUM(10)                                    UCON
               C                                                                  UCON
               C---COMMON                                                         UCON
  ISN 0015            COMMON TP,XNDT,SOME,SOMD,E,AO,COME,COMD,CI,XLMG             UCON
  ISN 0016            COMMON DUM1,DUM2,SI,OFST,DUM3,DUM4,DUM5,DOP                 UCON
  ISN 0017            COMMON REF                                                  UCON
  ISN 0018            COMMON DE,DA,DN,DTK,ELAT,ELON,GEOH,HEAD,RATE,IDAY,MDAY,ETIM UCON
  ISN 0019            COMMON DLAT,DLON,SMXE,SELV,FLAT,FLON,FFRQ,RSQ,VN            UCON
  ISN 0020            COMMON I,J,K,L,M,N,NDOP,ITER                                UCON
  ISN 0021            COMMON T,TEMP,A,DUM                                         UCON
               C                                                                  UCON
  ISN 0022            COMMON /COMC/NULL,IONE,ITWO,IFUR,I15,I30,I365,IM,KM,KF      UCON
  ISN 0023            COMMON /COMC/TAW,WAVE,CVCG,EFRQ,OMGE,XOSQ,ZOSQ,ZERO         UCON
  ISN 0024            COMMON /COMC/ONE,TWO,THRE,FOUR,FIVE,ATE,TEN,D60,HUND        UCON
  ISN 0025            COMMON /COMC/C480,S7P5,TUPI,DTRA,DTOM                       UCON
  ISN 0026            COMMON /COMC/TM1,TM4,TM5,TM7,TM8,CMTR,CKRM,C2K,C2M,REFC     UCON
               C                                                                  UCON
  ISN 0027            EQUIVALENCE (REF(1),Y),(REF(2),Z)                           UCON
               C                                                                  UCON
  ISN 0028            Y=(TEMP/DTRA)+TM7                                           UCON
  ISN 0029            L=Y                                                         UCON
  ISN 0030            Z=L                                                         UCON
  ISN 0031            Y=DABS((Y-Z)*D60)                                           UCON
  ISN 0032            M=Y                                                         UCON
  ISN 0033            Z=M                                                         UCON
  ISN 0034            N=(Y-Z)/TM4                                                 UCON
  ISN 0035            RETURN                                                      UCON
  ISN 0036            END                                                         UCON
```

/ UCON / SIZE OF PROGRAM 0001A8 HEXADECIMAL BYTES PAGE 002

NAME	TAG		TYPE	ADD.	NAME	TAG		TYPE	ADD.	NAME	TAG		TYPE	ADD.	NAME	TAG		TYPE	ADD.
A		C	R*8	N.R.	E		C	R*8	N.R.	I		C	I*4	N.R.	J		C	I*4	N.R.
K		C	I*4	N.R.	L	SF	C	I*4	000304	M	SF	C	I*4	000308	N	S	C	I*4	00030C
T		C	R*8	N.R.	Y	SFA	CE	R*8	0000C8	Z	SFA	CE	R*8	0000D0	AO		C	R*8	N.R.
CI		C	R*8	N.R.	DA		C	R*8	N.R.	DE		C	R*8	N.R.	DN		C	R*8	N.R.
IM		C	I*4	N.R.	KF		C	I*4	N.R.	KM		C	I*4	N.R.	SI		C	R*8	N.R.
TP		C	R*8	N.R.	VN		C	R*8	N.R.	ATE		C	R*8	N.R.	C2K		C	R*8	N.R.
C2M		C	R*8	N.R.	DOP		C	R*8	N.R.	DTK		C	R*8	N.R.	DUM		C	R*8	N.R.
D60	FA	C	R*8	0000A0	I15		C	I*4	N.R.	I30		C	I*4	N.R.	ONE		C	R*8	N.R.
REF		CF	R*8	0000C8	RSQ		C	R*8	N.R.	TAW		C	R*8	N.R.	TEN		C	R*8	N.R.
TM1		C	R*8	N.R.	TM4	F	C	R*8	0000E0	TM5		C	R*8	N.R.	TM7	F	C	R*8	0000F0
TM8		C	R*8	N.R.	TWO		C	R*8	N.R.	CKRM		C	R*8	N.R.	CMTR		C	R*8	N.R.
COMD		C	R*8	N.R.	CONE		C	R*8	N.R.	CVCG		C	R*8	N.R.	C480		C	R*8	N.R.
DLAT		C	R*8	N.R.	DLON		C	R*8	N.R.	DTOM		C	R*8	N.R.	DTRA	F	C	R*8	0000C8
DUM1		C	R*8	N.R.	DUM2		C	R*8	N.R.	DUM3		C	R*8	N.R.	DUM4		C	R*8	N.R.
DUM5		C	R*8	N.R.	EFRQ		C	R*8	N.R.	ELAT		C	R*8	N.R.	ELON		C	R*8	N.R.
ETIM		C	R*8	N.R.	FFRQ		C	R*8	N.R.	FIVE		C	R*8	N.R.	FLAT		C	R*8	N.R.
FLON		C	R*8	N.R.	FOUR		C	R*8	N.R.	GEOH		C	R*8	N.R.	HEAD		C	R*8	N.R.
HUND		C	R*8	N.R.	IDAY		C		N.R.	IFOR		C	I*4	N.R.	IONE		C	I*4	N.R.
ITER		C	I*4	N.R.	ITWO		C			I365		C	I*4	N.R.	MDAY		C	I*4	N.R.
NDOP		C	I*4	N.R.	NULL		C			OFST		C	R*8	N.R.	OMGE		C	R*8	N.R.
RATE		C	R*8	N.R.	REFC		C			SELV		C	R*8	N.R.	SMXE		C	R*8	N.R.
SOMD		C	R*8	N.R.	SONE		C			S7P5		C	R*8	N.R.	TEMP	F	C	R*8	000320
THRE		C	R*8	N.R.	TOPI		C			UCON			R*4	00008C	WAVE		C	R*8	N.R.
XLMG		C	R*8	N.R.	XNDT		C	R*8		XOSQ		C	R*8	N.R.	ZERO		C	R*8	N.R.
ZOSQ		C	R*8	N.R.															

***** COMMON INFORMATION *****

NAME OF COMMON BLOCK * * SIZE OF BLOCK 0003D8 HEXADECIMAL BYTES

VAR. NAME	TYPE	REL. ADDR.	VAR. NAME	TYPE	REL. ADDR.	VAR. NAME	TYPE	REL. ADDR.	VAR. NAME	TYPE	REL. ADDR.
TP	R*8	N.R.	XNDT	R*8	N.R.	SONE	R*8	N.R.	SOMD	R*8	N.R.
E	R*8	N.R.	AO	R*8	N.R.	CONE	R*8	N.R.	COMD	R*8	N.R.
CI	R*8	N.R.	XLMG	R*8	N.R.	DUM1	R*8	N.R.	DUM2	R*8	N.R.
SI	R*8	N.R.	OFST	R*8	N.R.	DUM3	R*8	N.R.	DUM4	R*8	N.R.
DUM5	R*8	N.R.	DOP	R*8	N.R.	REF	R*8	0000C8	DE	R*8	N.R.
DA	R*8	N.R.	DN	R*8	N.R.	DTK	R*8	N.R.	ELAT	R*8	N.R.
ELON	R*8	N.R.	GEOH	R*8	N.R.	HEAD	R*8	N.R.	RATE	R*8	N.R.
IDAY	I*4	N.R.	MDAY	I*4	N.R.	ETIM	R*8	N.R.	DLAT	R*8	N.R.
DLON	R*8	N.R.	SMXE	R*8	N.R.	SELV	R*8	N.R.	FLAT	R*8	N.R.
FLON	R*8	N.R.	FFRQ	R*8	N.R.	RSQ	R*8	N.R.	VN	R*8	N.R.
I	I*4	N.R.	J	I*4	N.R.	K	I*4	N.R.	L	I*4	000304
M	I*4	000308	N	I*4	00030C	NDOP	I*4	N.R.	ITER	I*4	N.R.
T	R*8	N.R.	TEMP	R*8	000320	A	R*8	N.R.	DUM	R*8	N.R.

EQUIVALENCED VARIABLES WITHIN THIS COMMON BLOCK

VARIABLE	OFFSET	VARIABLE	OFFSET	VARIABLE	OFFSET	VARIABLE	OFFSET
Y	0000C8	Z	0000D0				

NAME OF COMMON BLOCK * COMC* SIZE OF BLOCK 000128 HEXADECIMAL BYTES

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VAR. NAME	TYPE	REL. ADDR.	VAR. NAME	TYPE	REL. ADDR.	VAR. NAME	TYPE	REL. ADDR.	VAR. NAME	TYPE	REL. ADDR.
NULL	I*4	N.R.	IONE	I*4	N.R.	ITWO	I*4	N.R.	IFOR	I*4	N.R.
I15	I*4	N.R.	I30	I*4	N.R.	I365	I*4	N.R.	IM	I*4	N.R.
KM	I*4	N.R.	KF	I*4	N.R.	TAW	R*8	N.R.	WAVE	R*8	N.R.
CVCG	R*8	N.R.	EFRQ	R*8	N.R.	OMGE	R*8	N.R.	XOSQ	R*8	N.R.
ZOSQ	R*8	N.R	ZERO	R*8	N.R.	ONE	R*8	N.R.	TWO	R*8	N.R.
THRE	R*8	N.R.	FOUR	R*8	N.R.	FIVE	R*8	N.R.	ATE	R*8	N.R.
TEN	R*8	N.R.	D60	R*8	0000A0	HUND	R*8	N.R.	C480	R*8	N.R.
S7P5	R*8	N.R.	TOPI	R*8	N.R.	DTRA	R*8	0000C8	DTOM	R*8	N.R.
TM1	R*8	N.R.	TM4	R*8	0000E0	TM5	R*8	N.R.	TM7	R*8	0000F0
TM8	R*8	N.R.	CMTR	R*8	N.R.	CKRM	R*8	N.R.	C2K	R*8	N.R.
C2K	R*8	N.R.	REFC	R*8	N.R.						

OPTIONS IN EFFECT NAME= MAIN,OPT=02,LINECNT=58,SIZE=0000K,

OPTIONS IN EFFECT SOURCE,EBCDIC,NOLIST,NODECK,LOAD,MAP,NOEDIT,ID,NOXREF

STATISTICS SOURCE STATEMENTS = 35 ,PROGRAM SIZE = 424

STATISTICS NO DIAGNOSTICS GENERATED

****** END OF COMPILATION ****** 61K BYTES OF CORE NOT USED

STATISTICS NO DIAGNOSTICS THIS STEP

9. REFERENCES

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3. Naval Ship Systems Command, Ship Systems Command Contract Specification Radio Navigation Set, AN/SRN-9, SHIPS-R-5111, 28 January 1966.

4. Naval Ship Systems Command, Ship Systems Command Contract Specification Radio Navigation Set, AN/SRN-9 ( ), SHIPS-R-5111A, 29 January 1968 (supersedes SHIPS-R-5111).

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8. E. Liverette, "Preliminary System Operational Procedures for the AN/SRN-9, 9A Radio Navigation Receivers and CP-967/UYK Digital Data Computer," APL/JHU S3E-70-391, December 1970.

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10. Magnavox Company, Operation and Maintenance Manual for University of California Navigation Satellite Receiver Set 702CA, TP68-2040, 30 June 1968.

11. H. S. Hopfield, "A Two-Quartic Refractivity Profile for the Troposphere for Correcting Satellite Data," Journal of Geophysical Research, Vol. 74, 1969, 4487-4499.

12. U. S. Navy, Marine Climatic Atlas of the World, NAVAER 50-10-529, 1956.

13. U. S. Department of Commerce and U. S. Department of the Navy (Office of Climatology and Oceanographic Analysis), Climatological and Oceanographic Atlas for Mariners, 1961.

14. S. M. Yionoulis, "Algorithm to Compute Tropospheric Refraction Effects on Range Measurements," Journal of Geophysical Research, Vol. 75, 20 December 1970, 7636-7637.

15. H. S. Hopfield, "Tropospheric Effect on Electromagnetically Measured Range: Prediction from Surface Weather Data," Radio Science, Vol. 6, 1971, 357-367.

16. C. Hastings, Approximations for Digital Computers, Princeton, 1955.

Appendix A

FLOW CHARTS FOR DATA PROCESSING PROGRAM AND FORTRAN NAVIGATION PROGRAM

Flow charts for the data processing program described in Section 6 are shown in Figs. A-1 through A-18. Flow charts for the navigation program described in Section 8 are shown in Figs. A-19 through A-25.

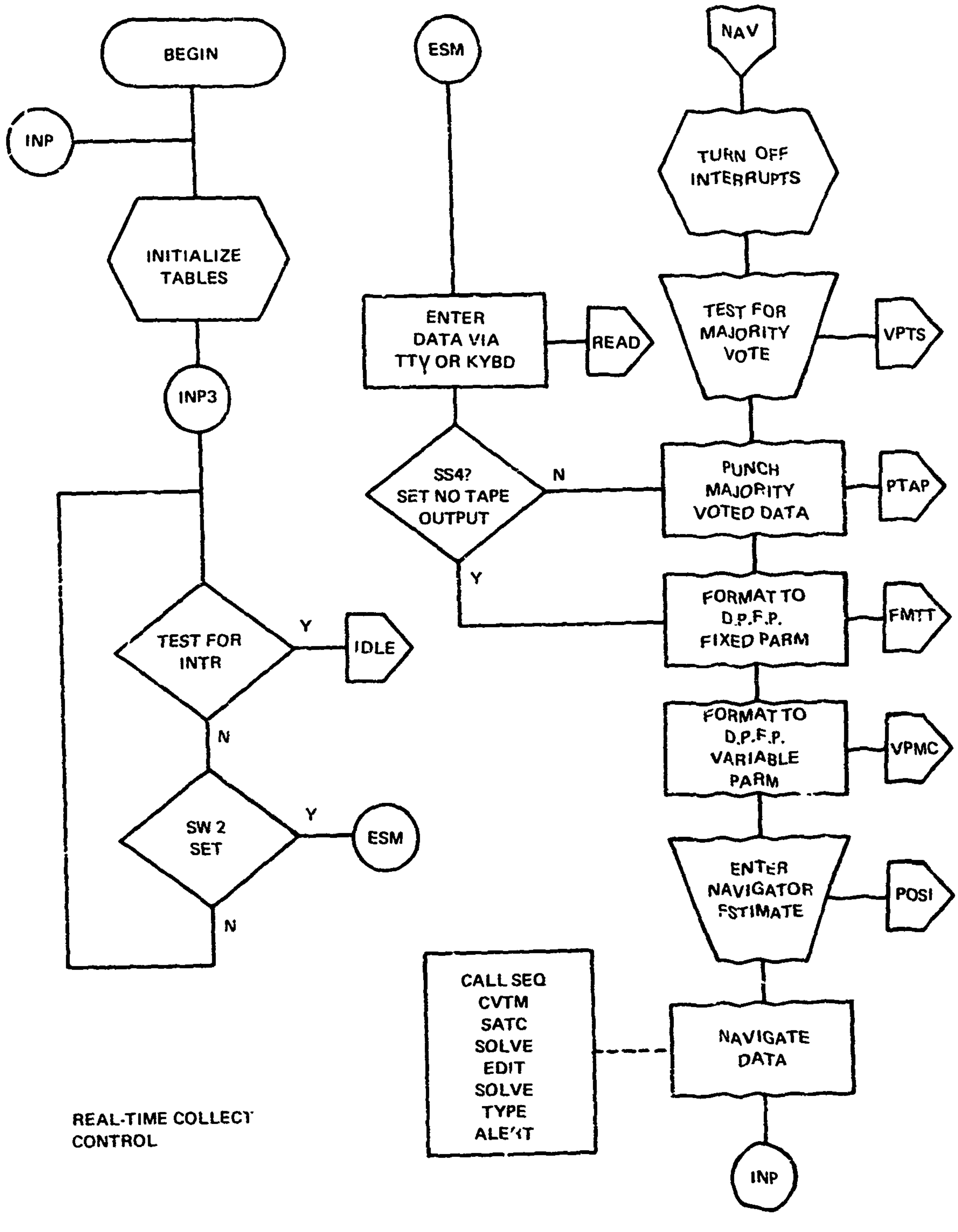

Fig. A-1 SUBROUTINES INP3, ESM, AND NAV

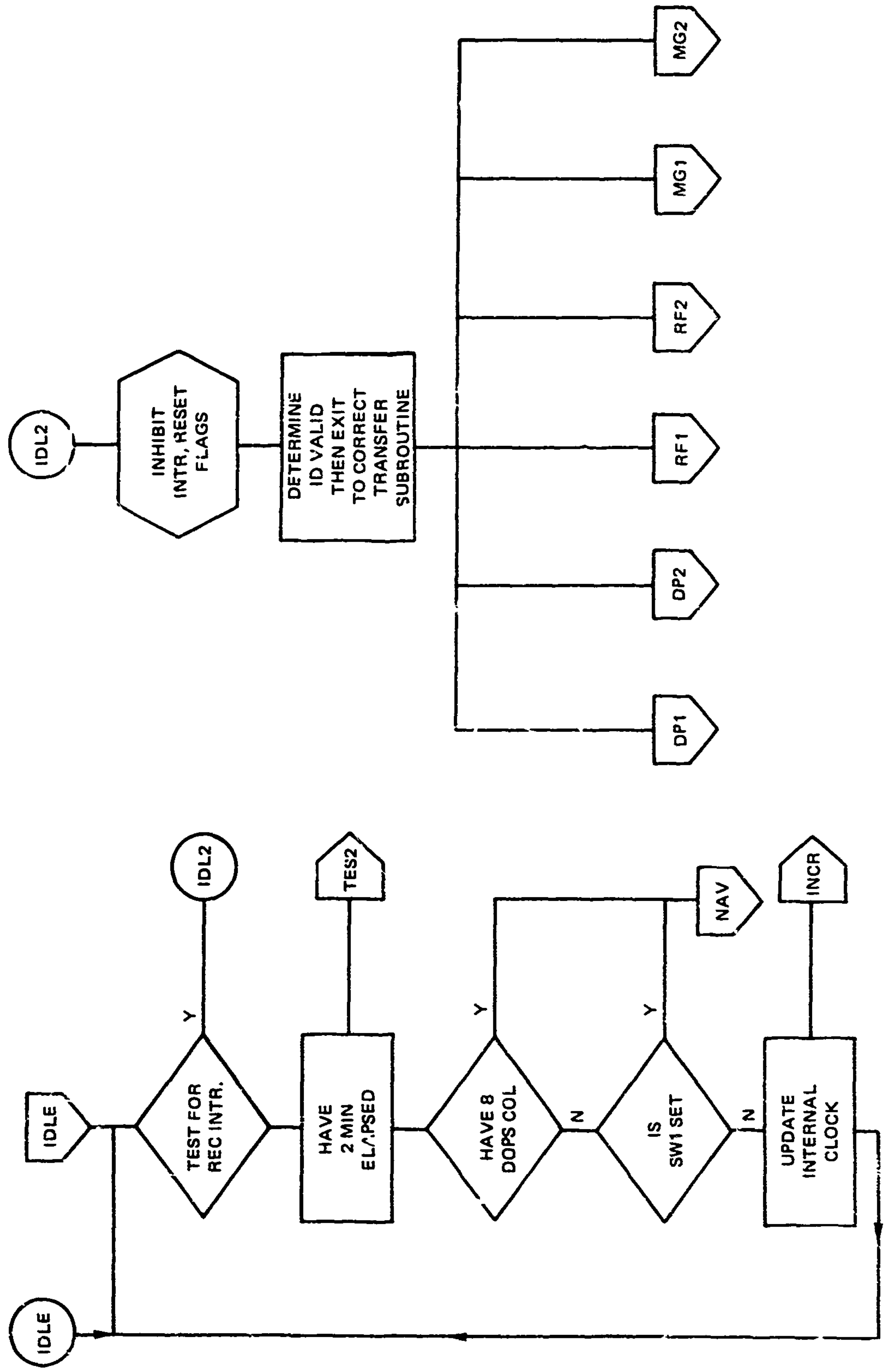

Fig. A-2 SUBROUTINES IDLE AND IDL2

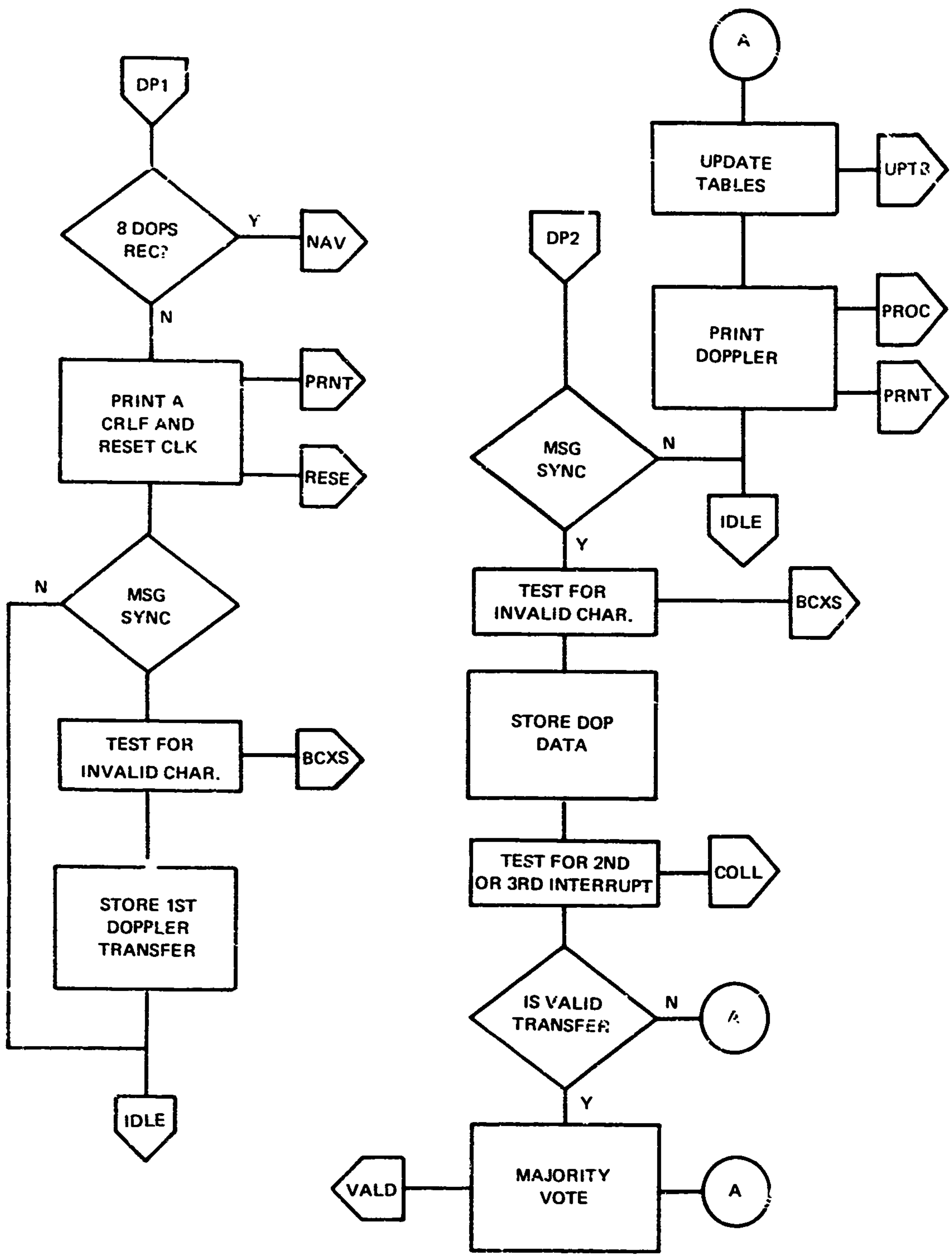

Fig. A-3 SUBROUTINES DP1 AND DP2

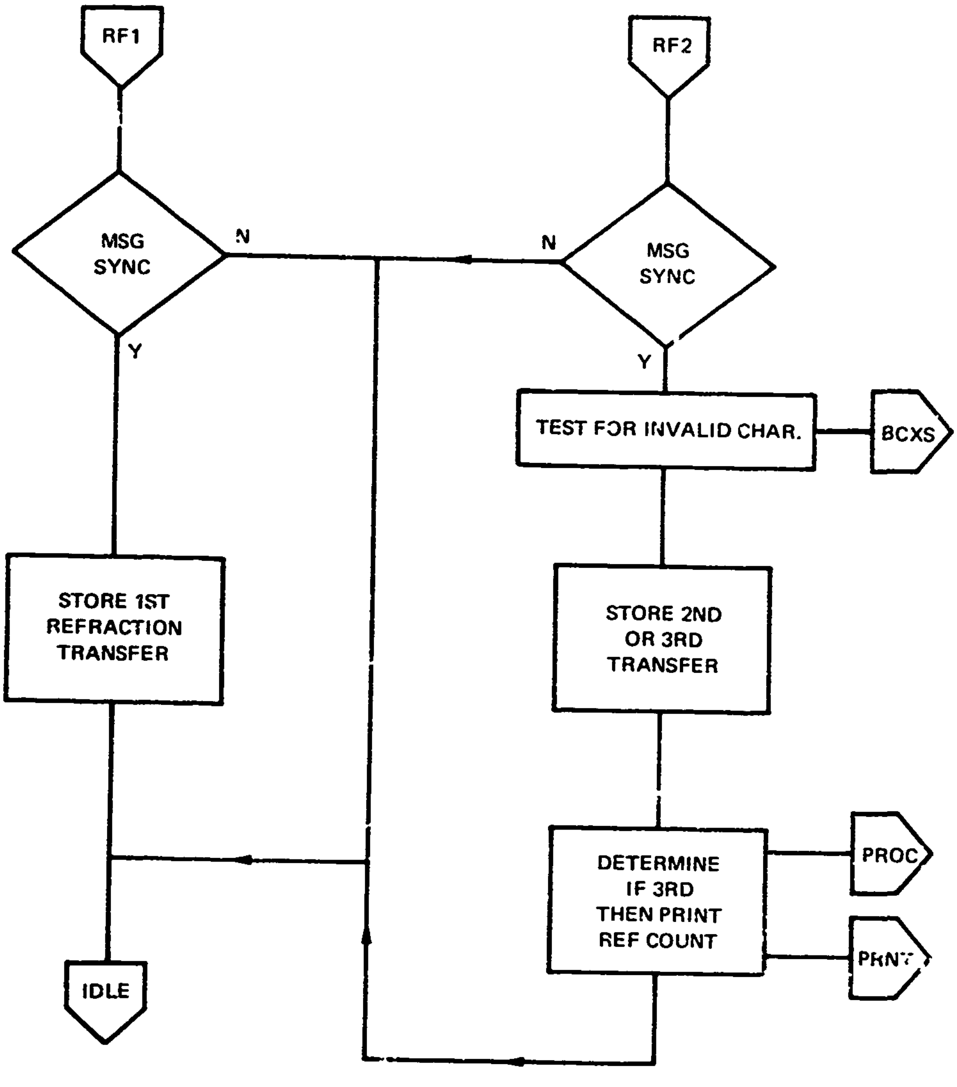

Fig. A-4 SUBROUTINES RF1 AND RF2

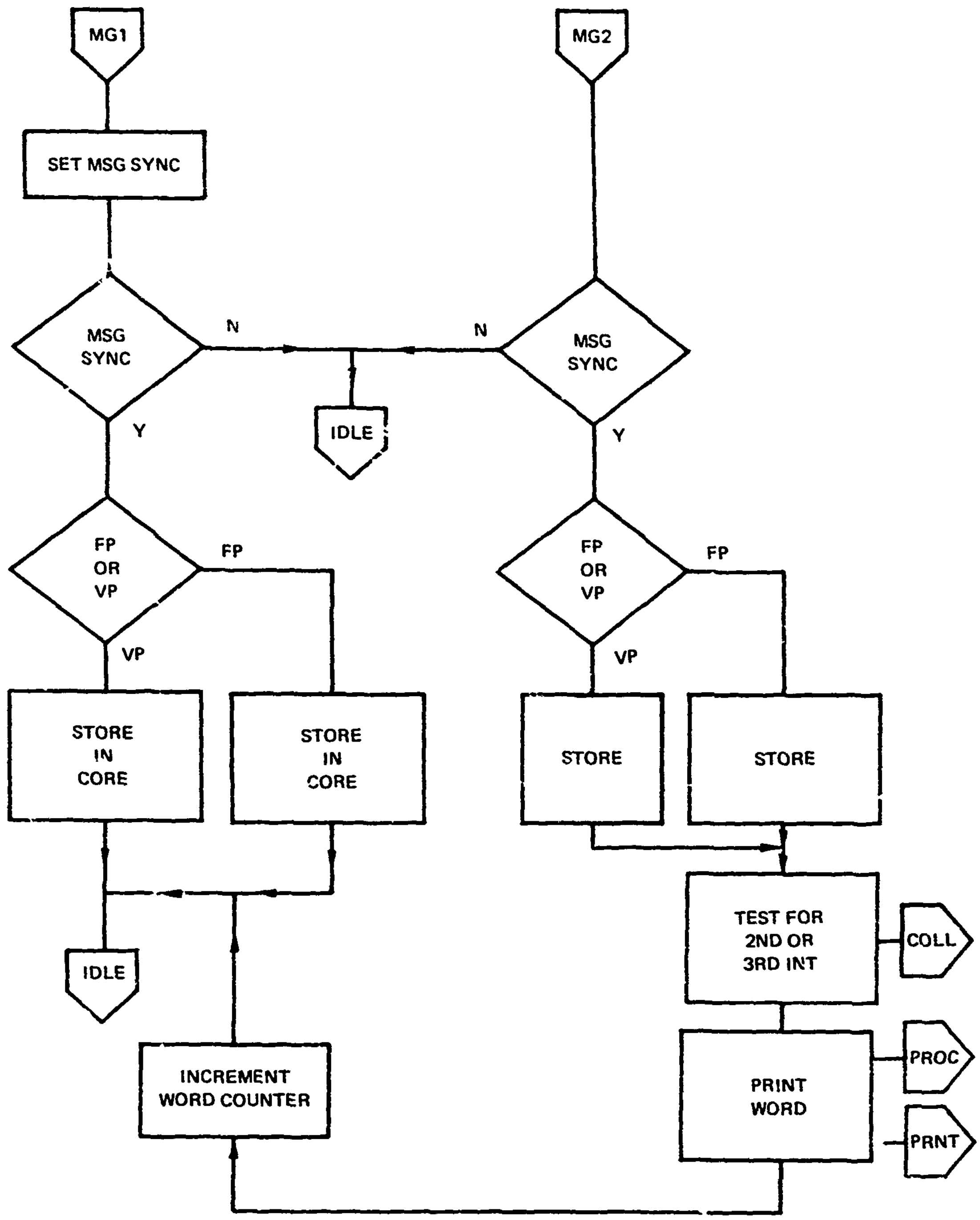

Fig. A-5 SUBROUTINES MG1 AND MG2

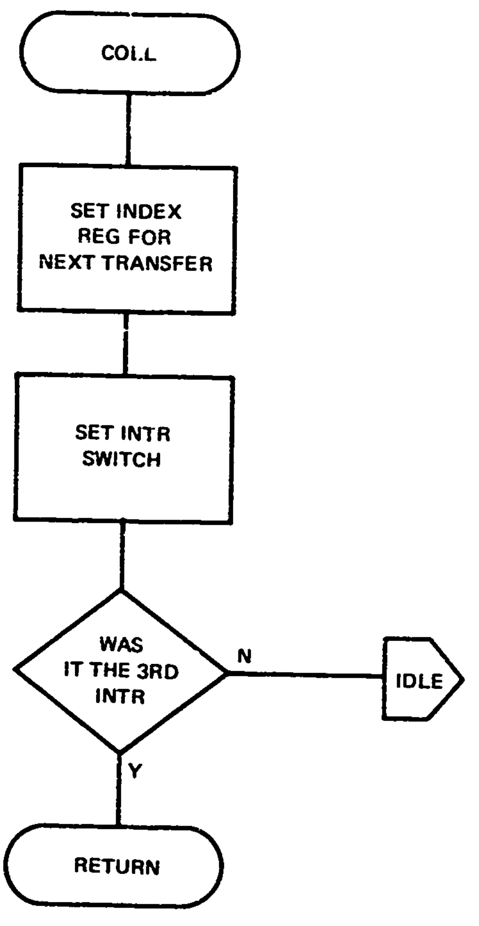

Fig. A-6 SUBROUTINE COLL

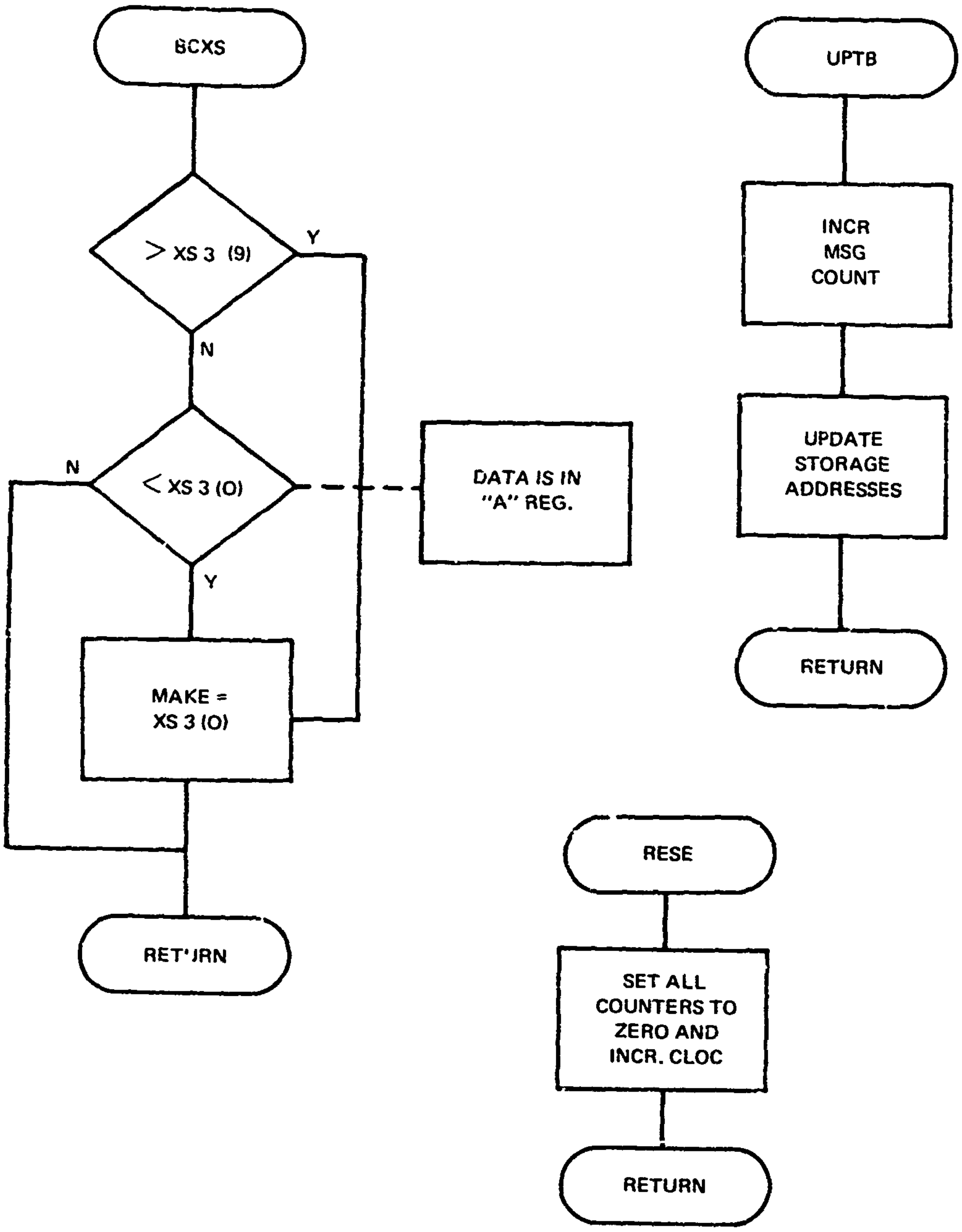

Fig. A-7 SUBROUTINES BCXS, UPTB, AND RESE

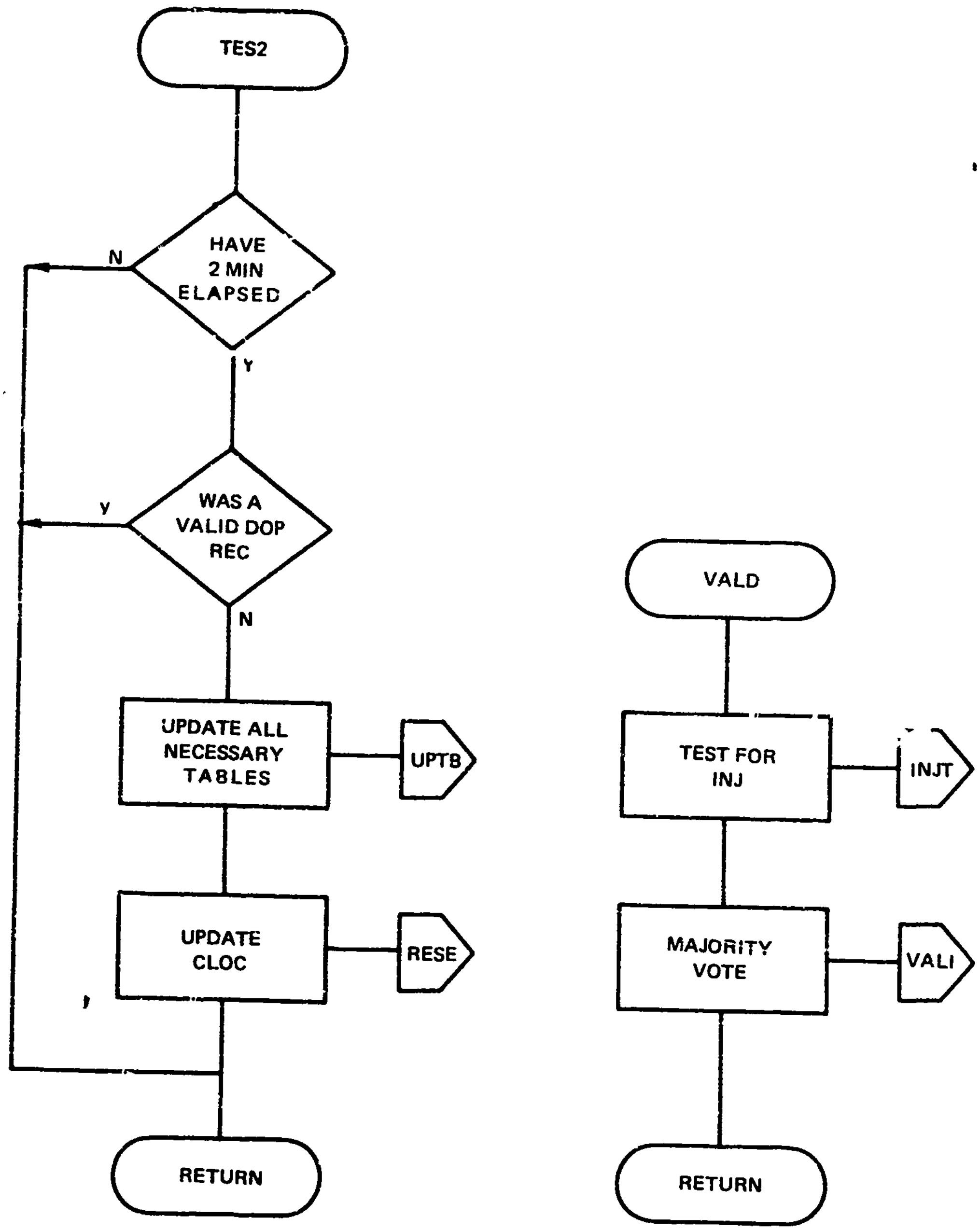

Fig. A-8 SUBROUTINES TES2 AND VALD

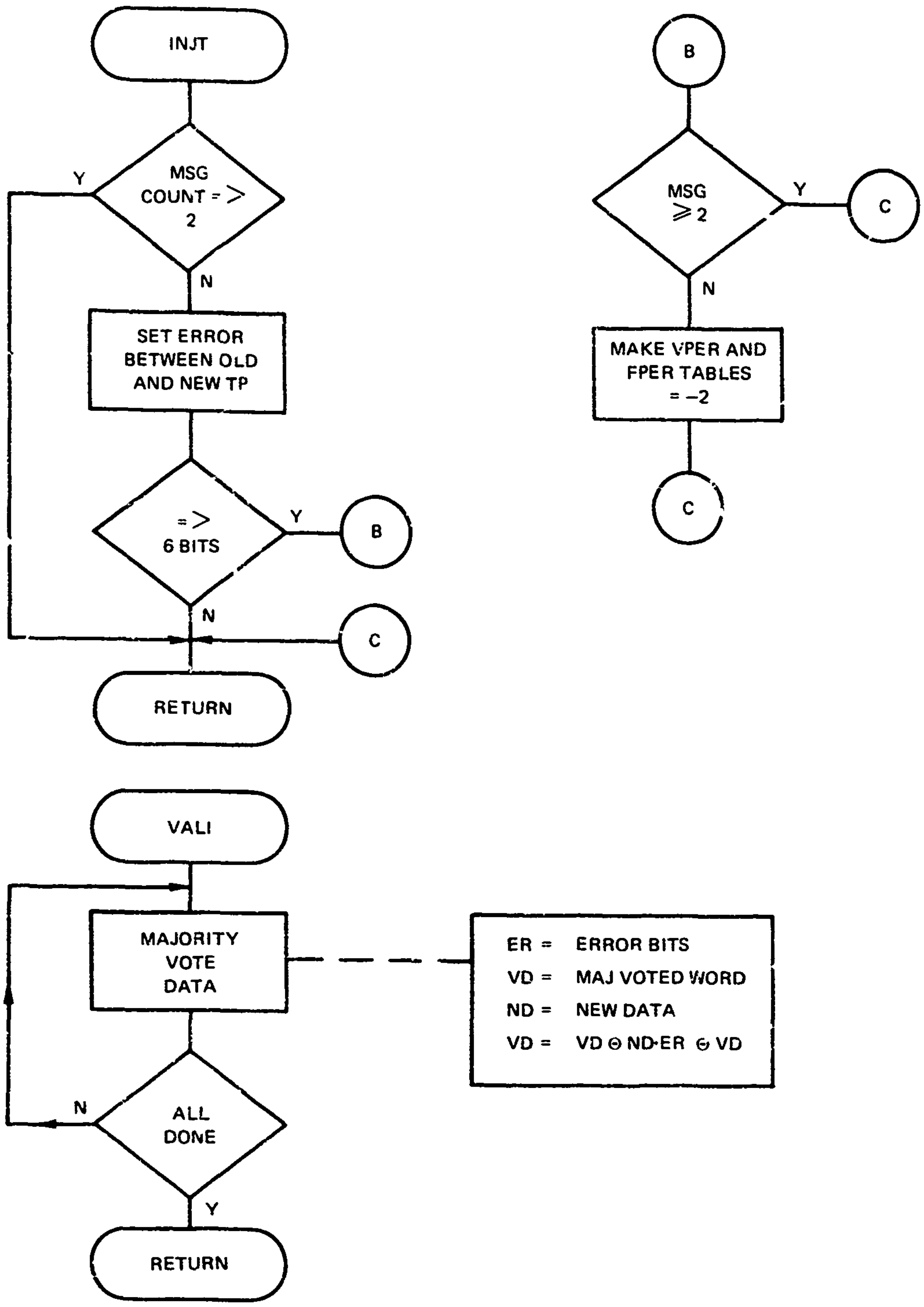

Fig. A-9 SUBROUTINES INJT AND VALI

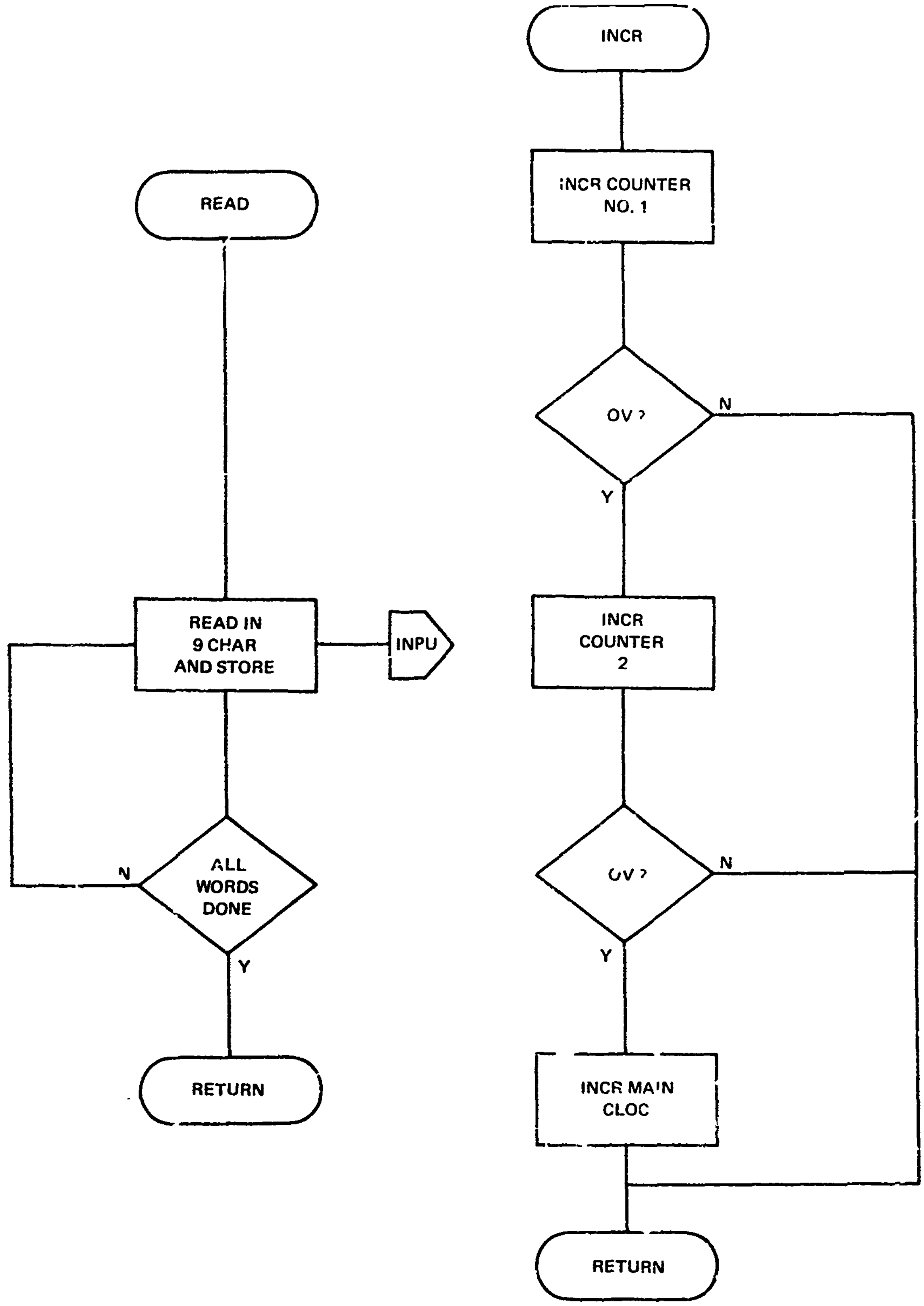

Fig. A-10 SUBROUTINES READ AND INCR

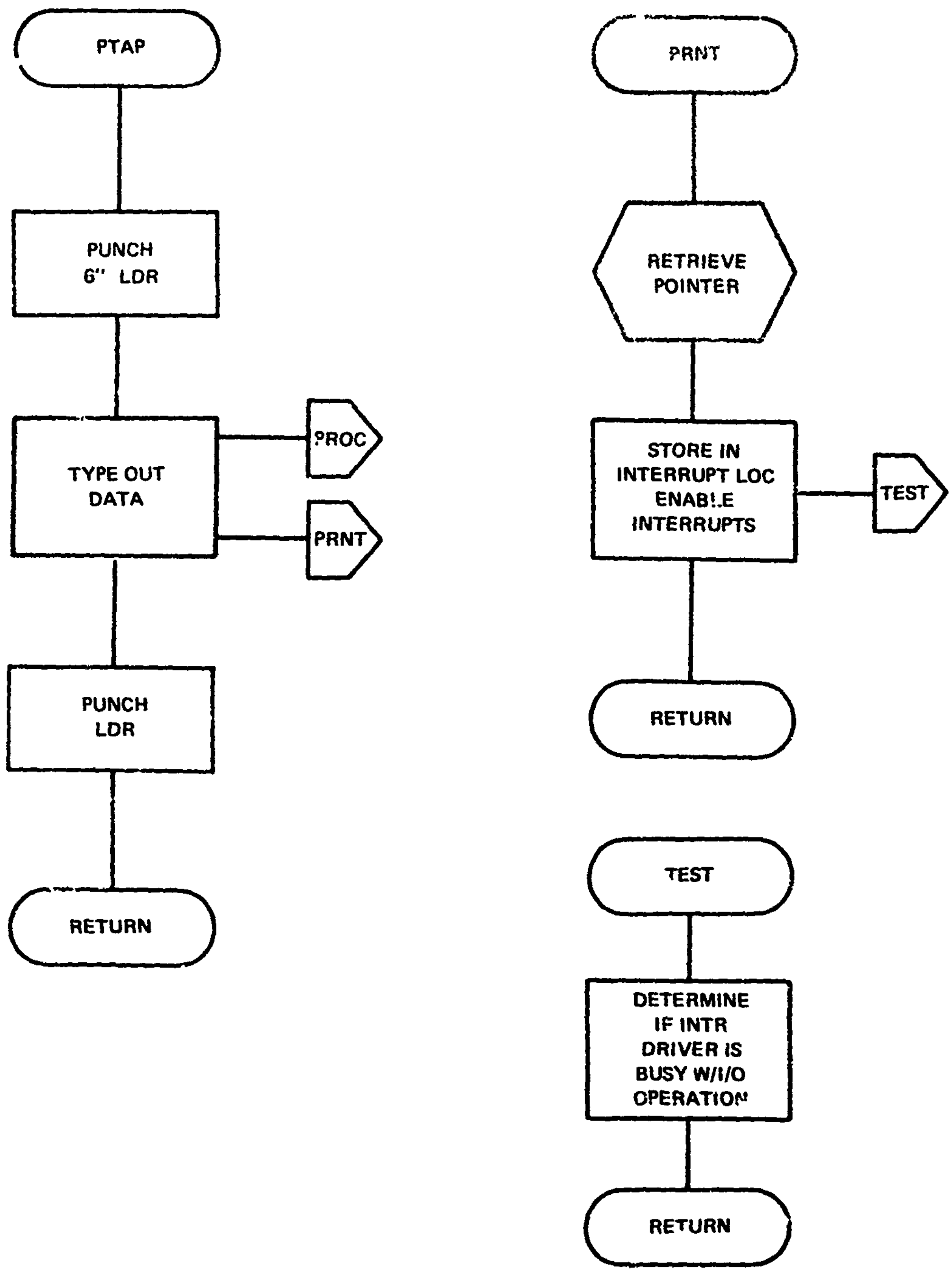

Fig. A-11 SUBROUTINES PTAP, PRNT, AND TEST

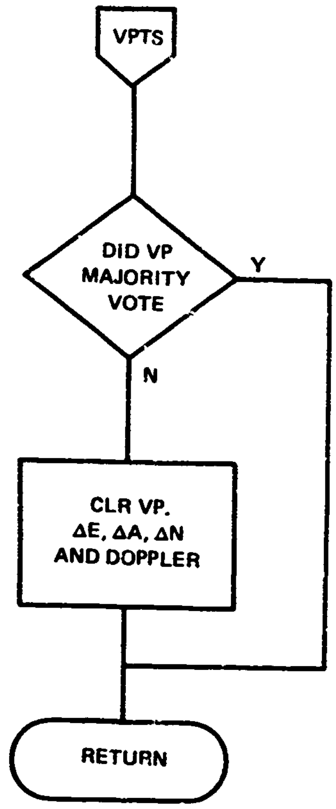

Fig. A-12 SUBROUTINE VPTS

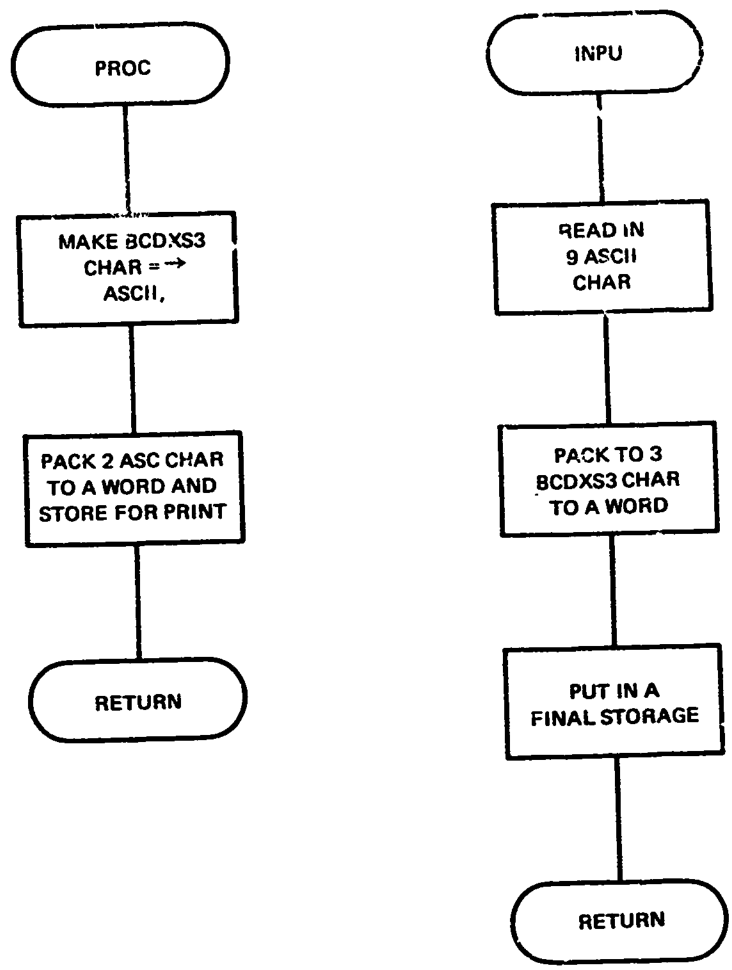

Fig. A-13 SUBROUTINES PROC AND INPU

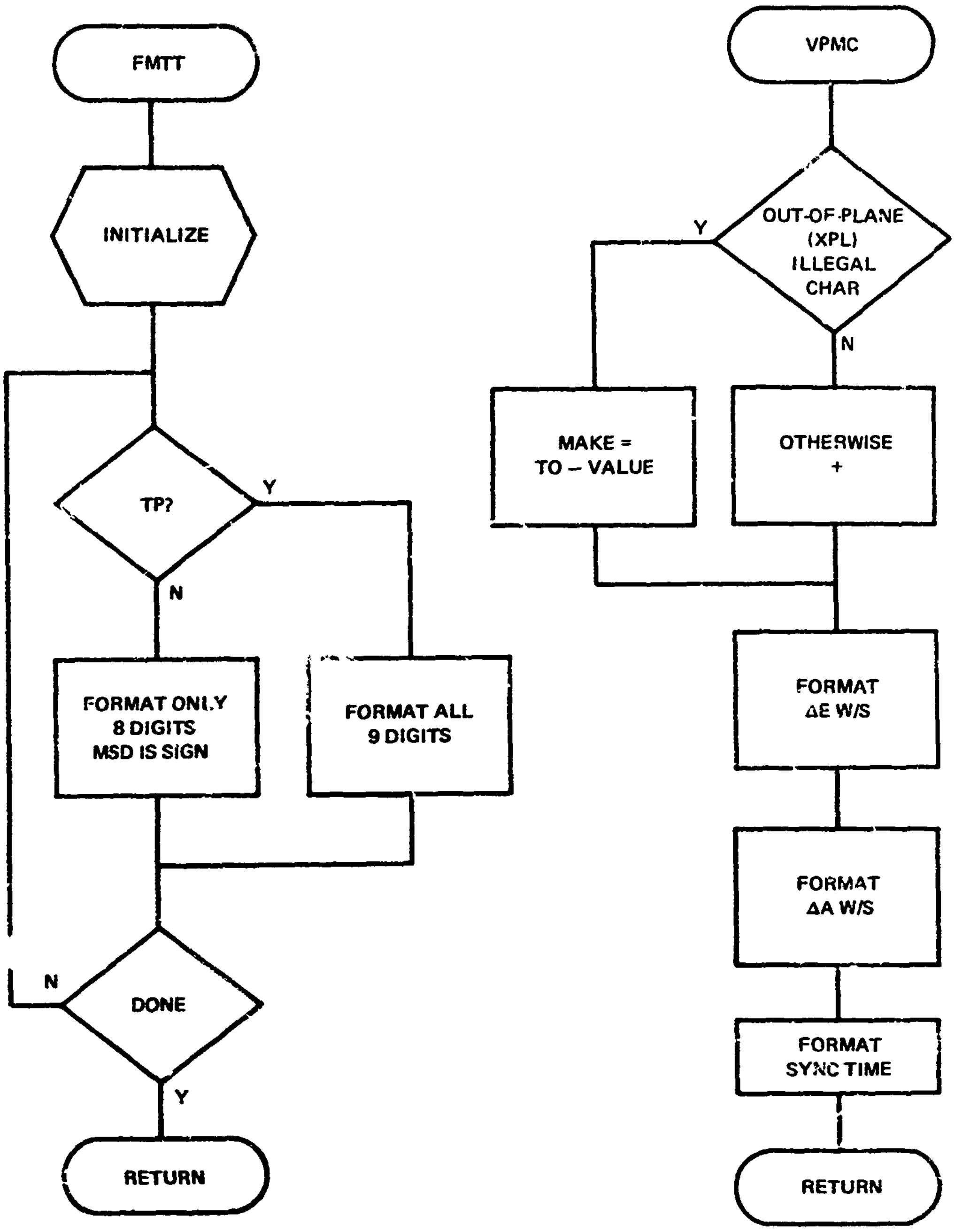

Fig. A-14 SUBROUTINES FMTT AND VPMC

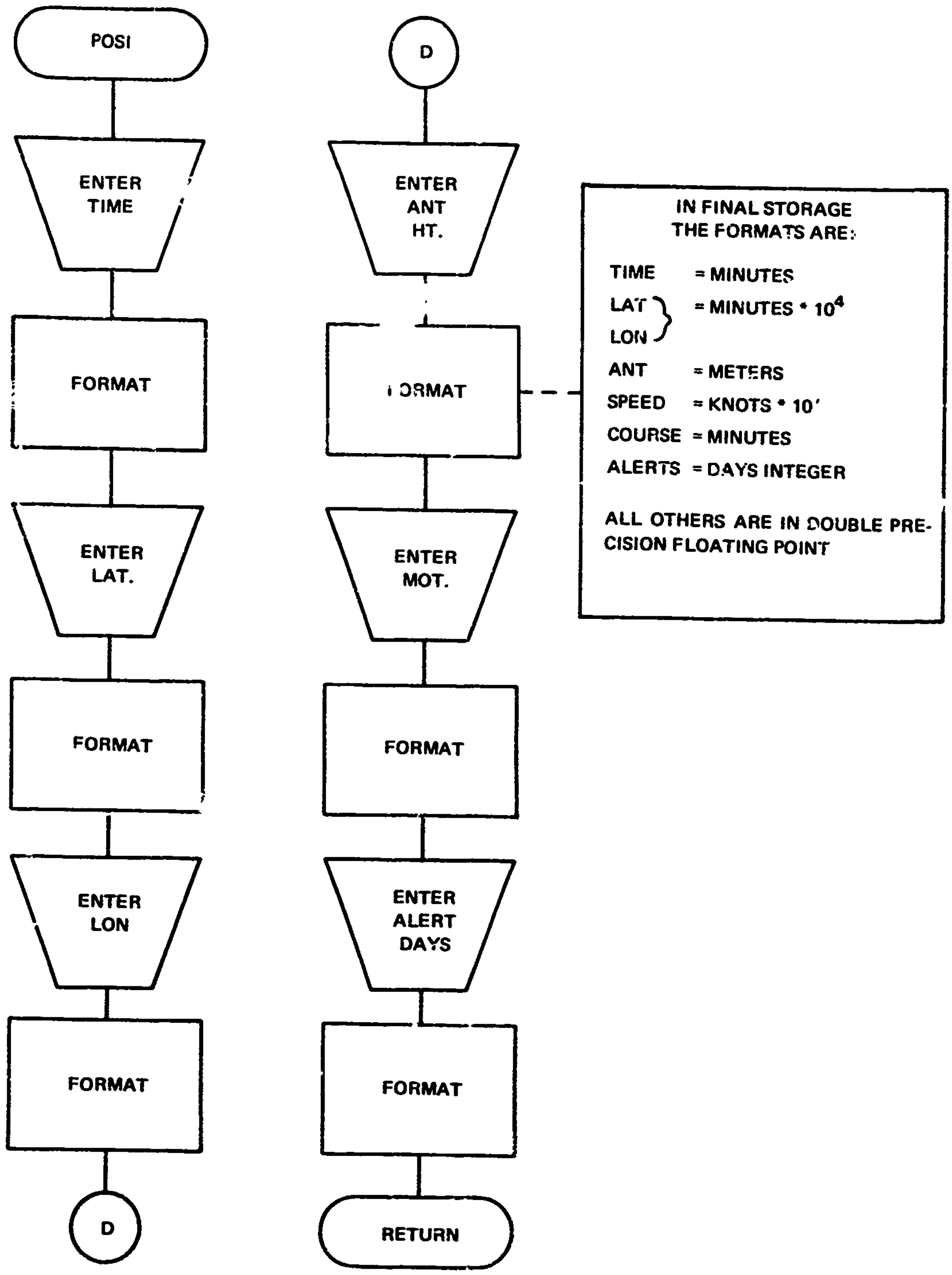

Fig. A-15 SUBROUTINE POSI

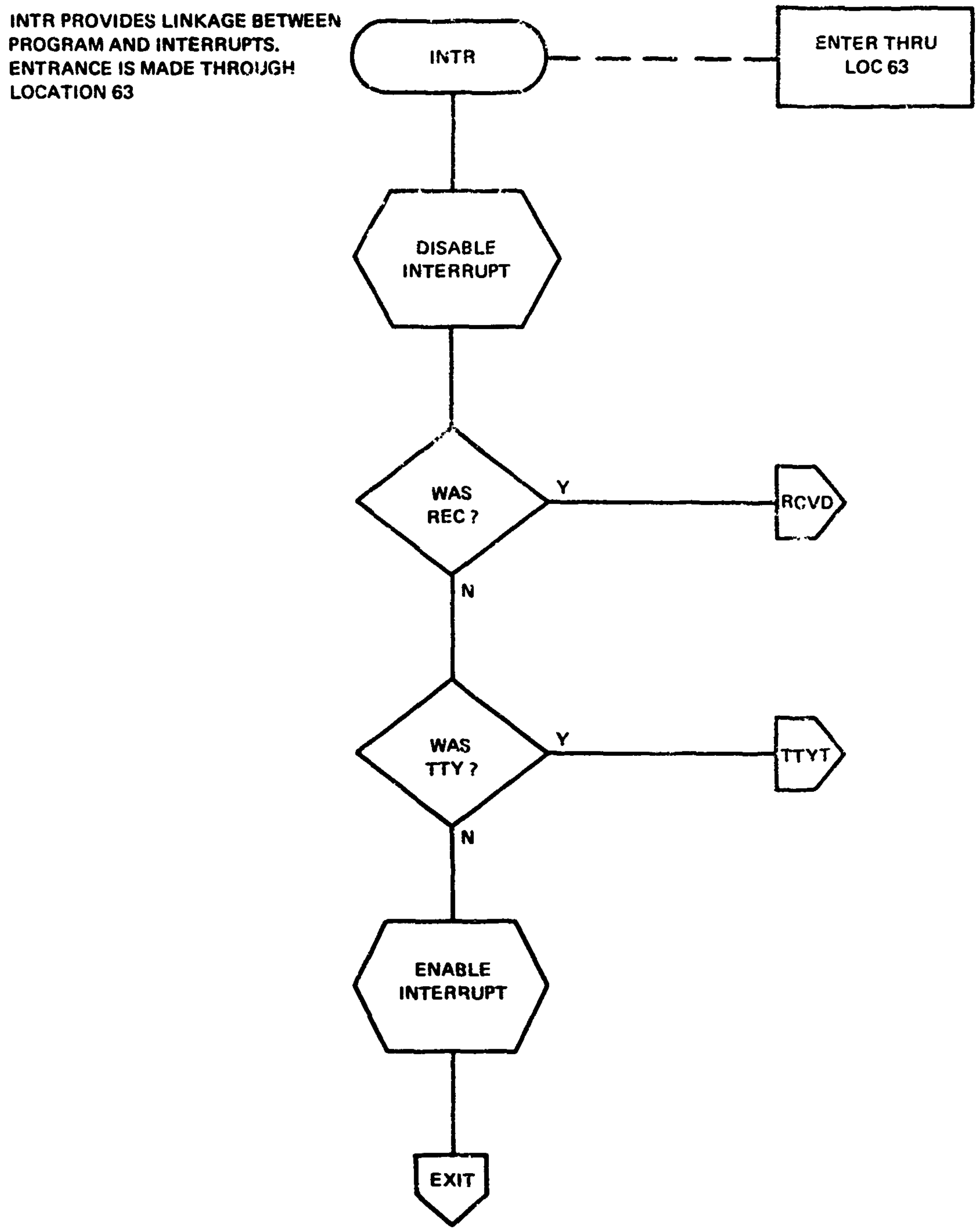

Fig. A-16 SUBROUTINE INTR

SUBROUTINE RCVD

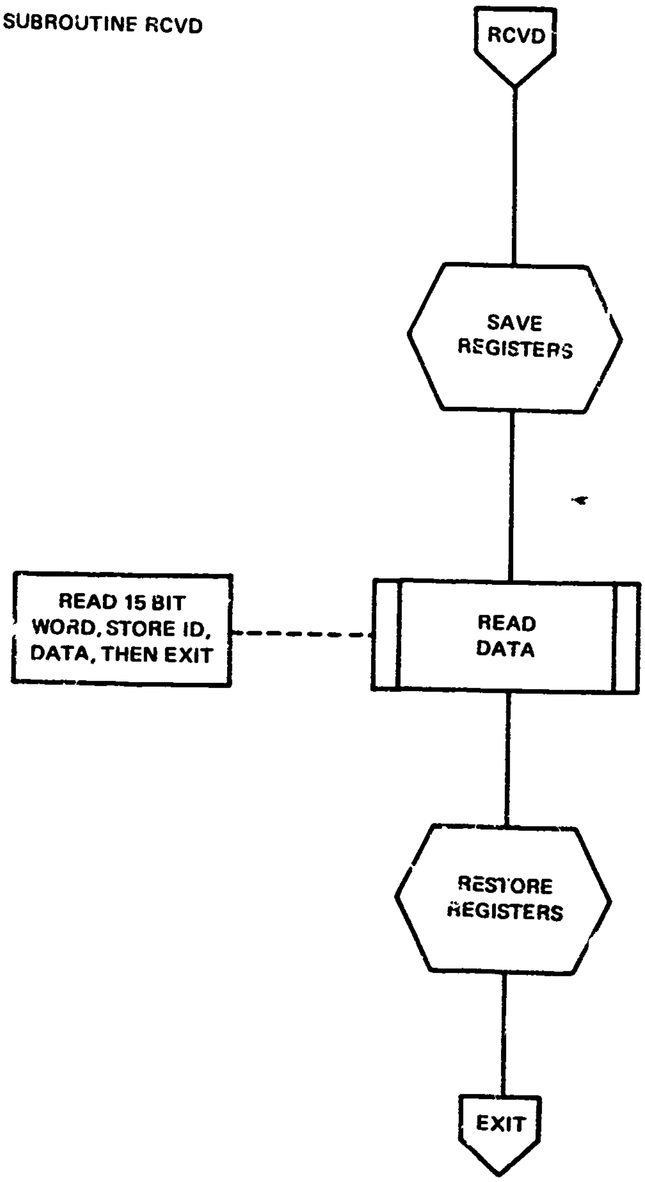

Fig. A-17 SUBROUTINE RCVD

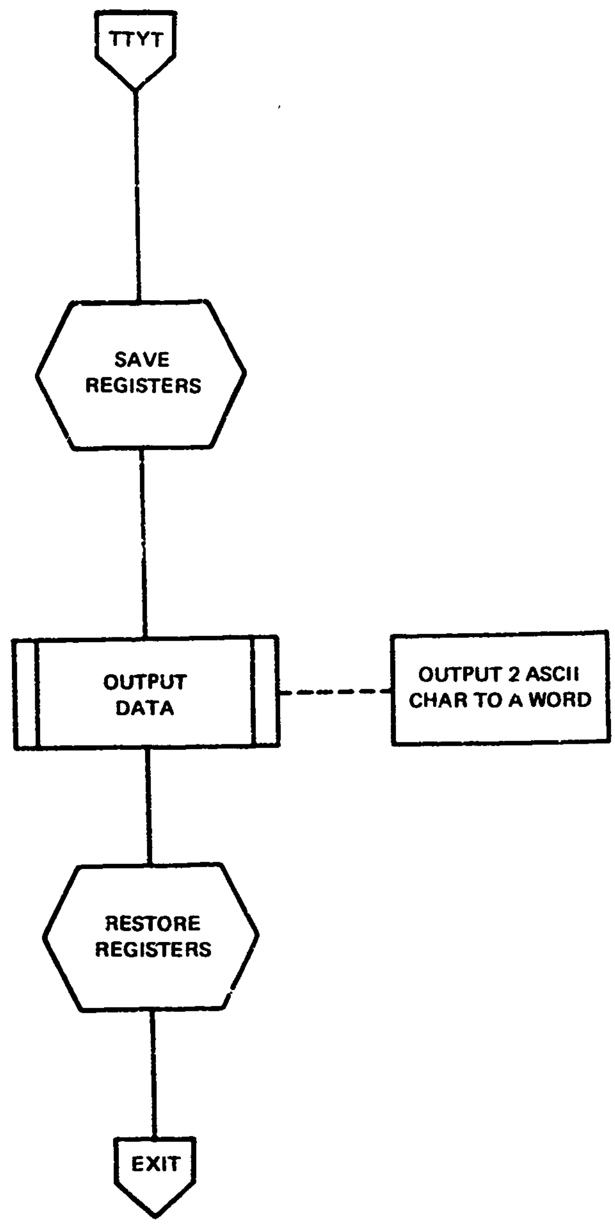

Fig. A-18 SUBROUTINE TTYT

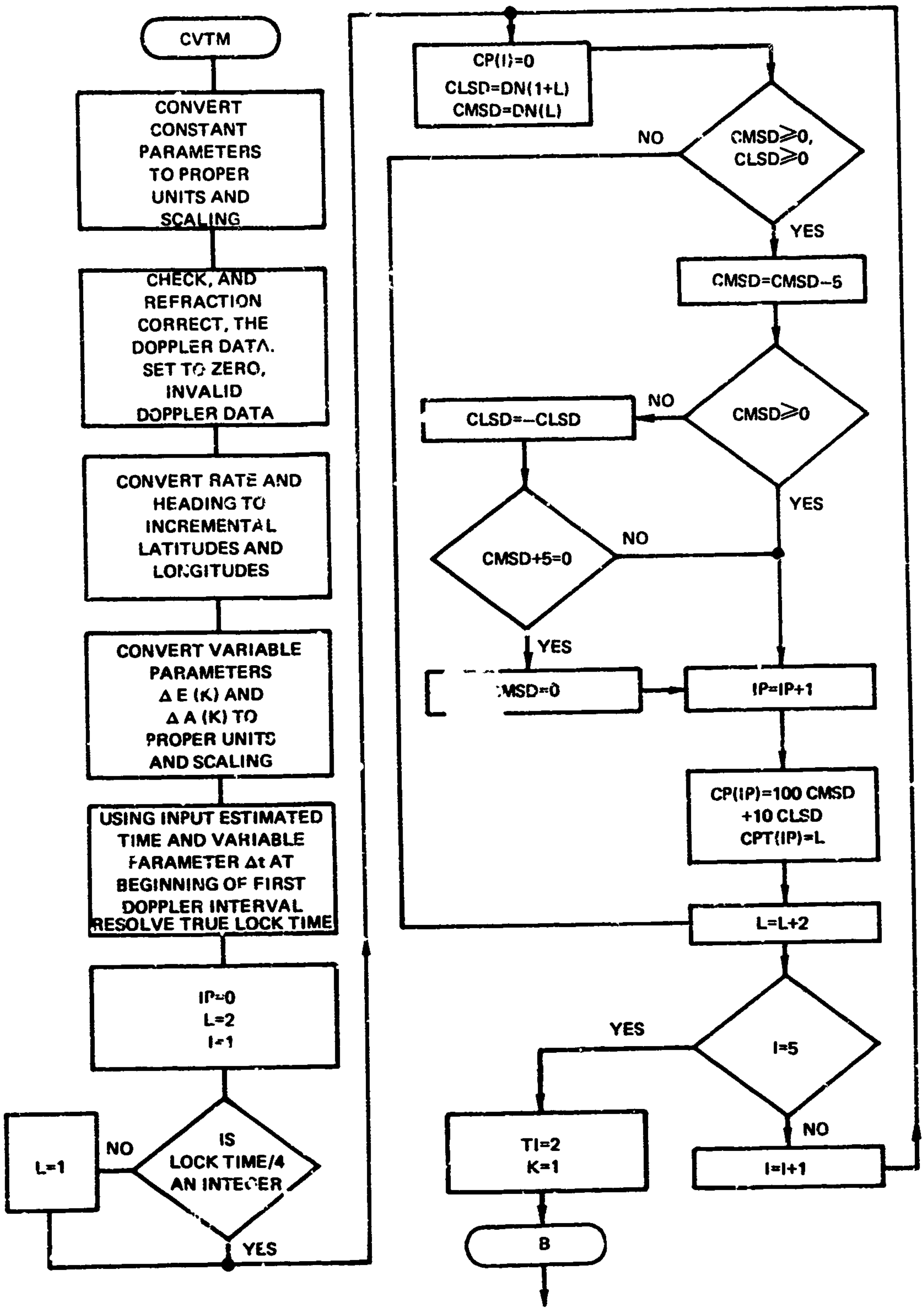

Fig. A-19 SUBROUTINE CVTM

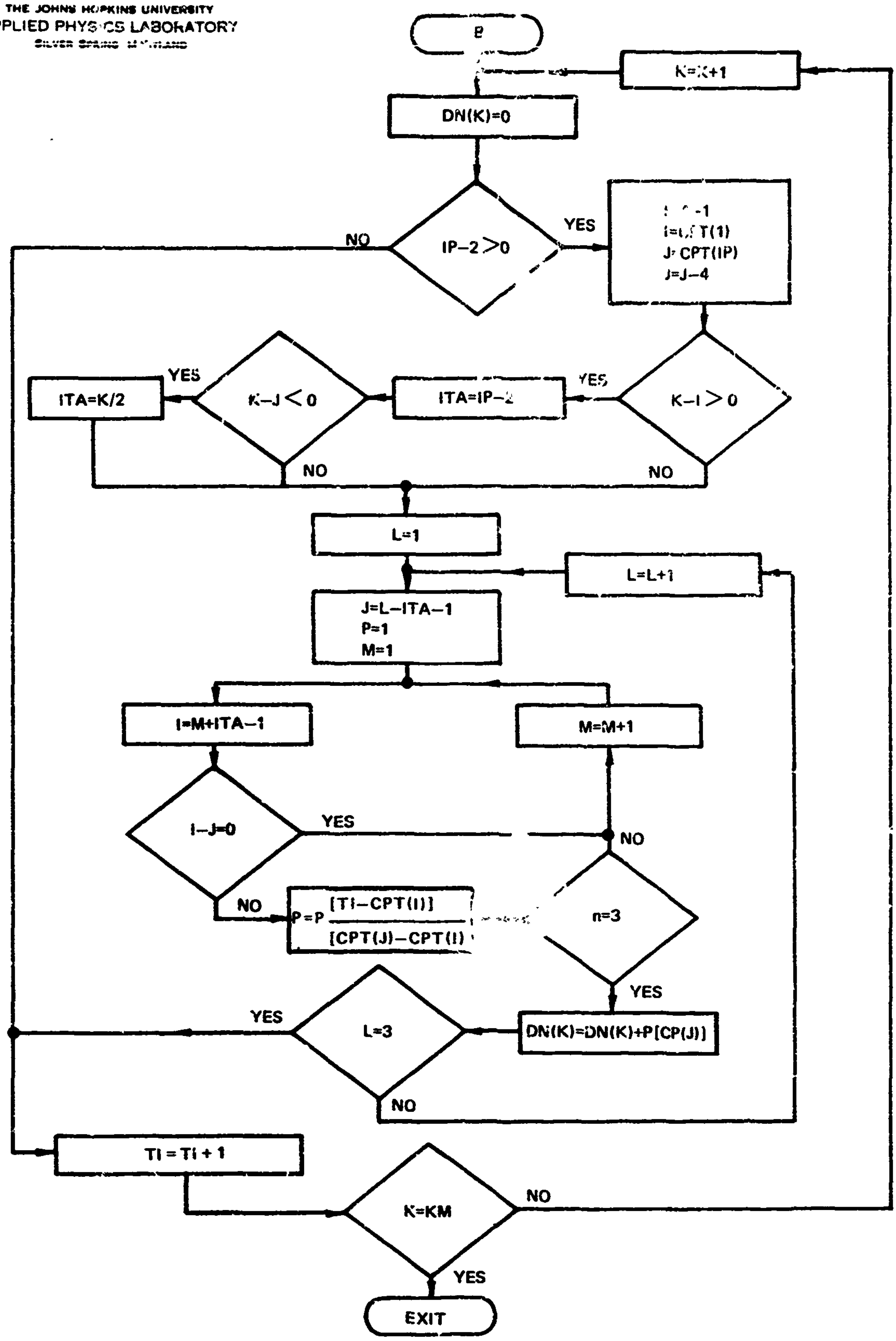

Fig. A-19 SUBROUTINE CVTM (cont'd)

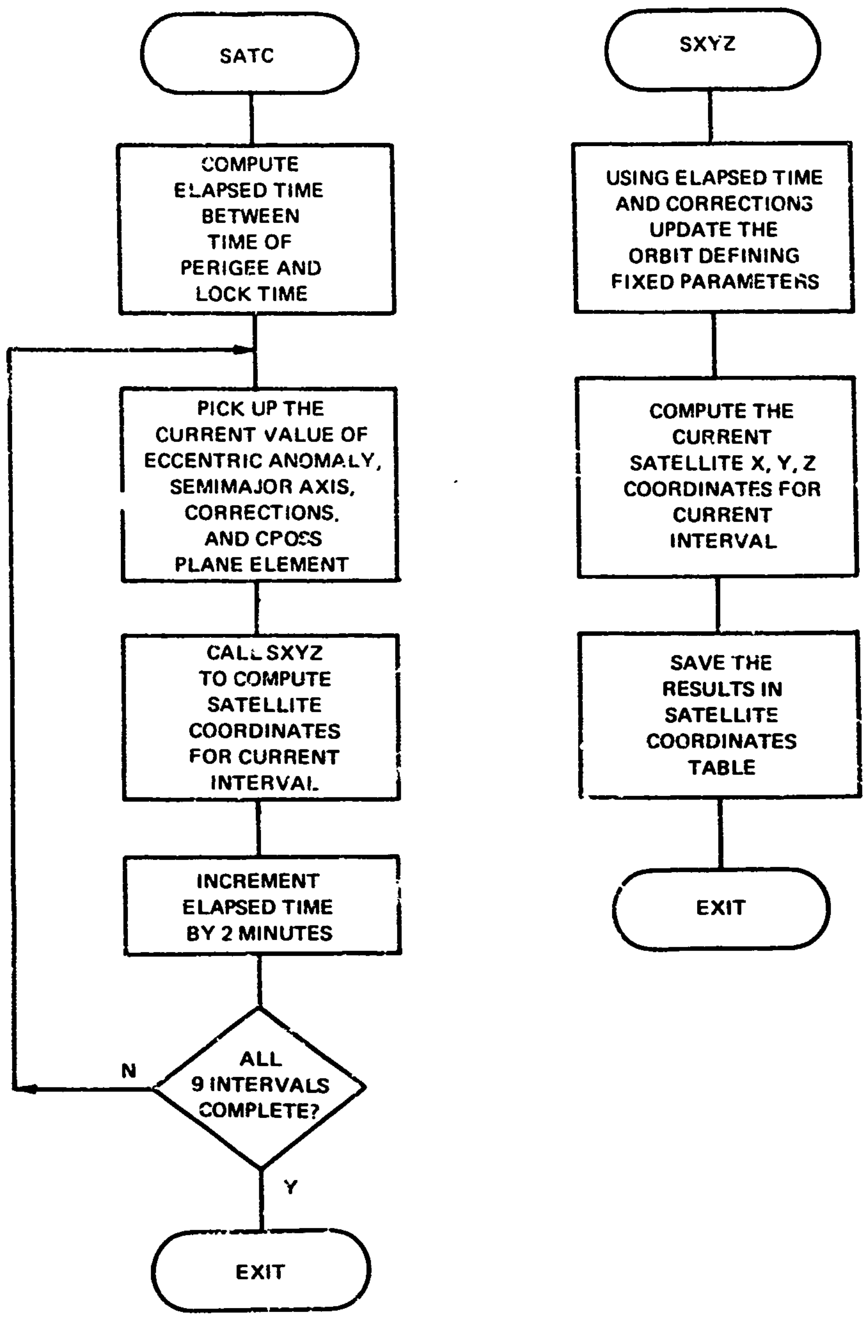

Fig. A-20 SUBROUTINES SATC AND SXYZ

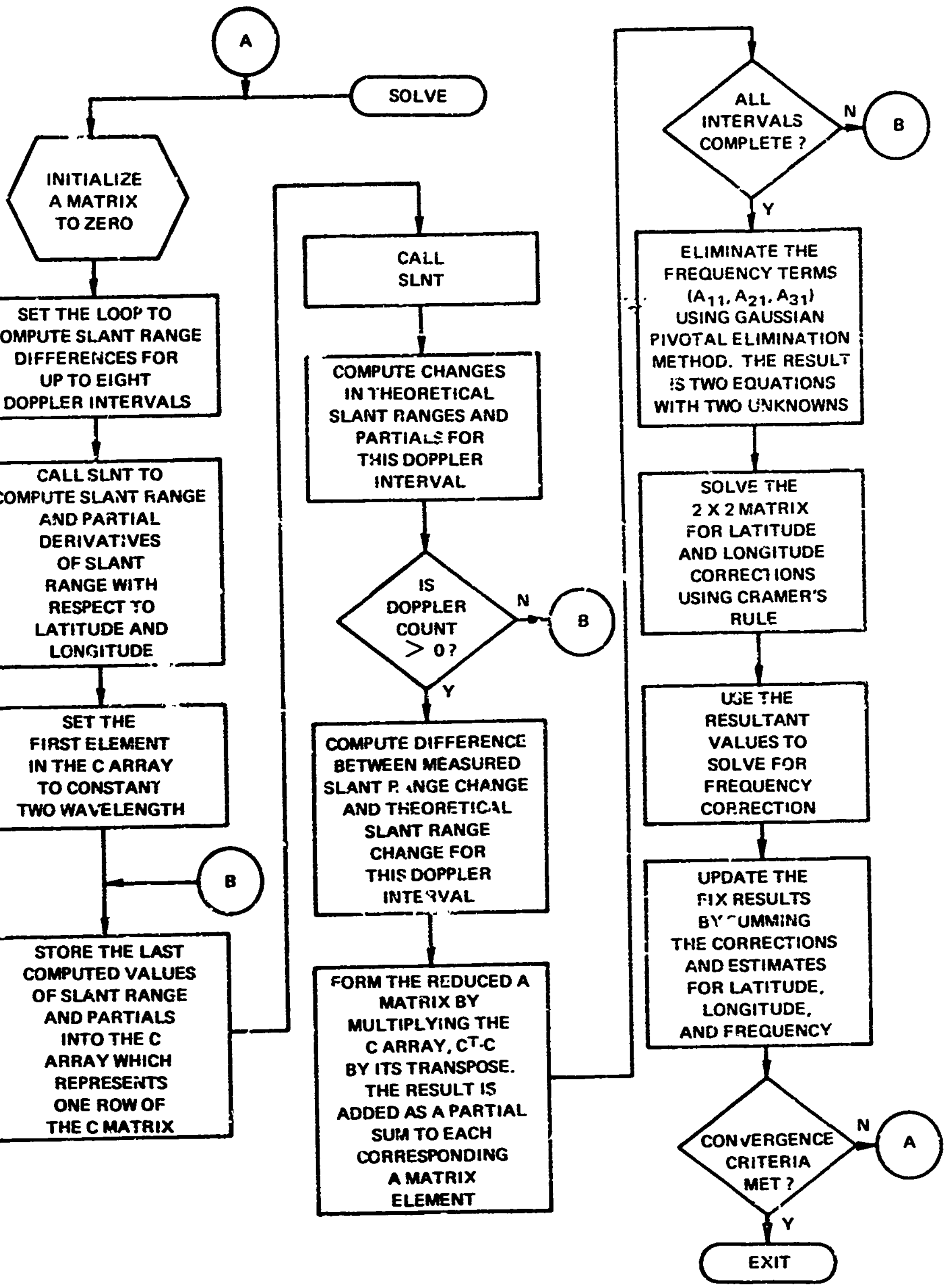

Fig. A-21 SUBROUTINE SOLVE

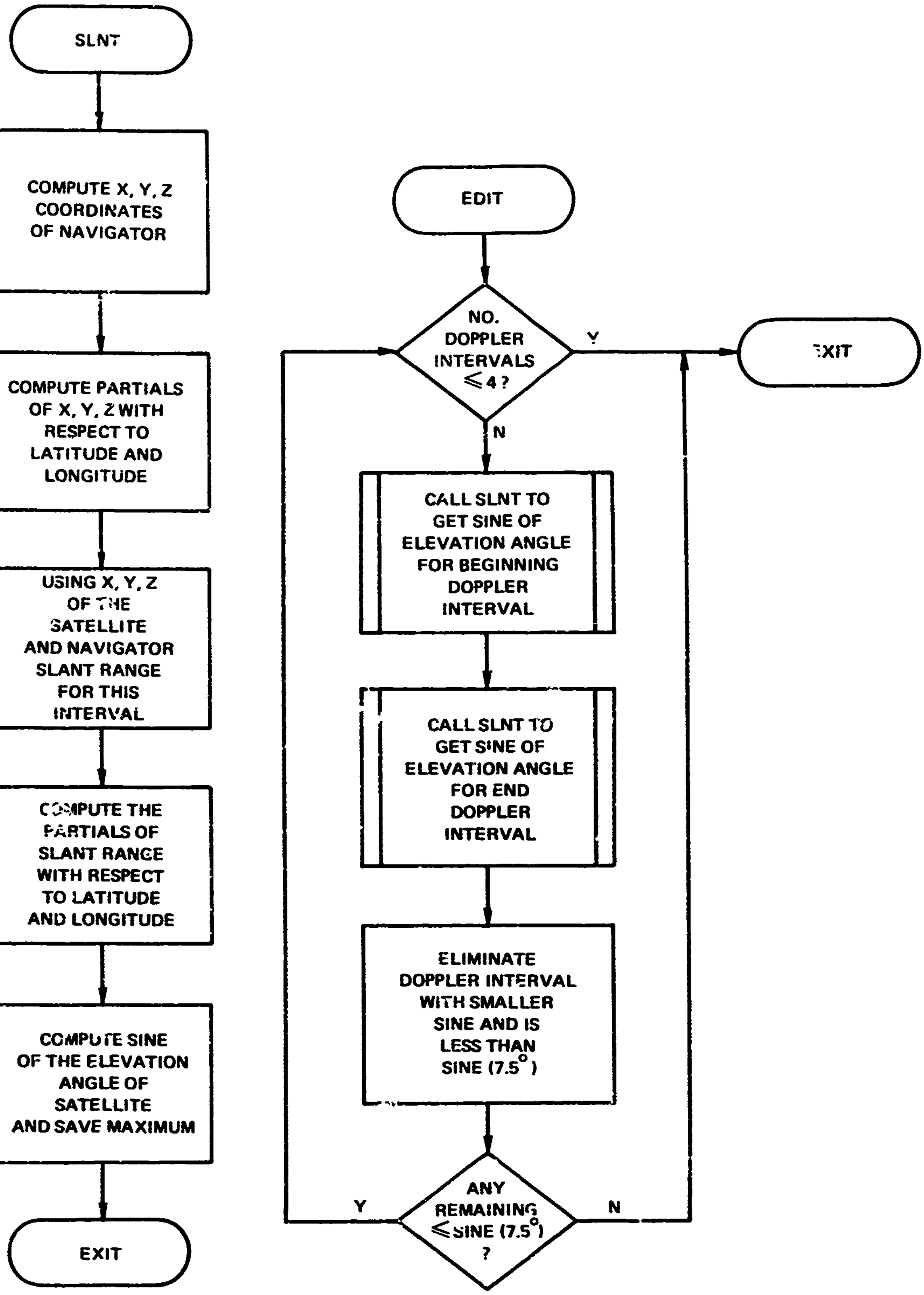

Fig. A-22 SUBROUTINES SLANT AND EDIT

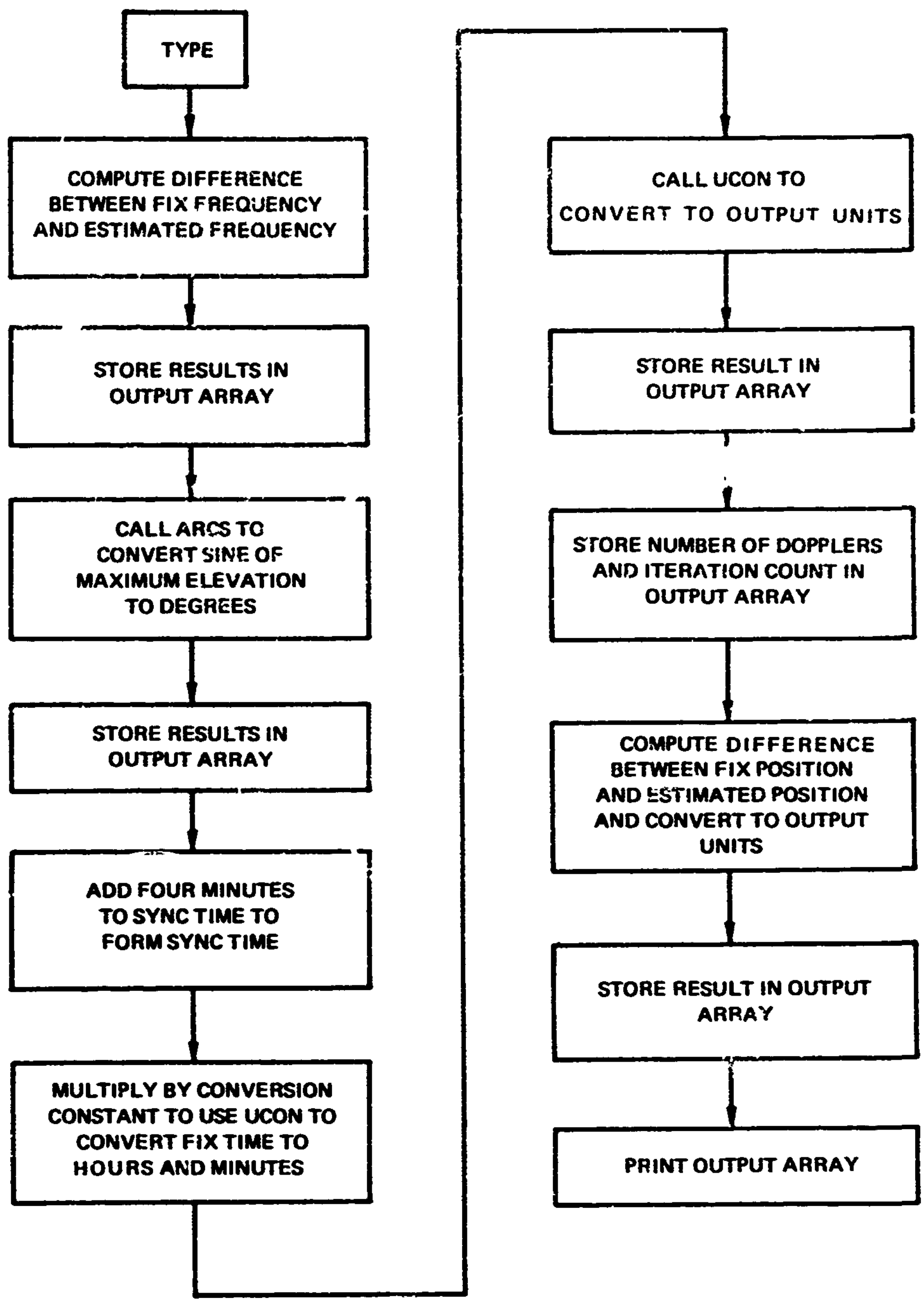

Fig. A-23 SUBROUTINE TYPE

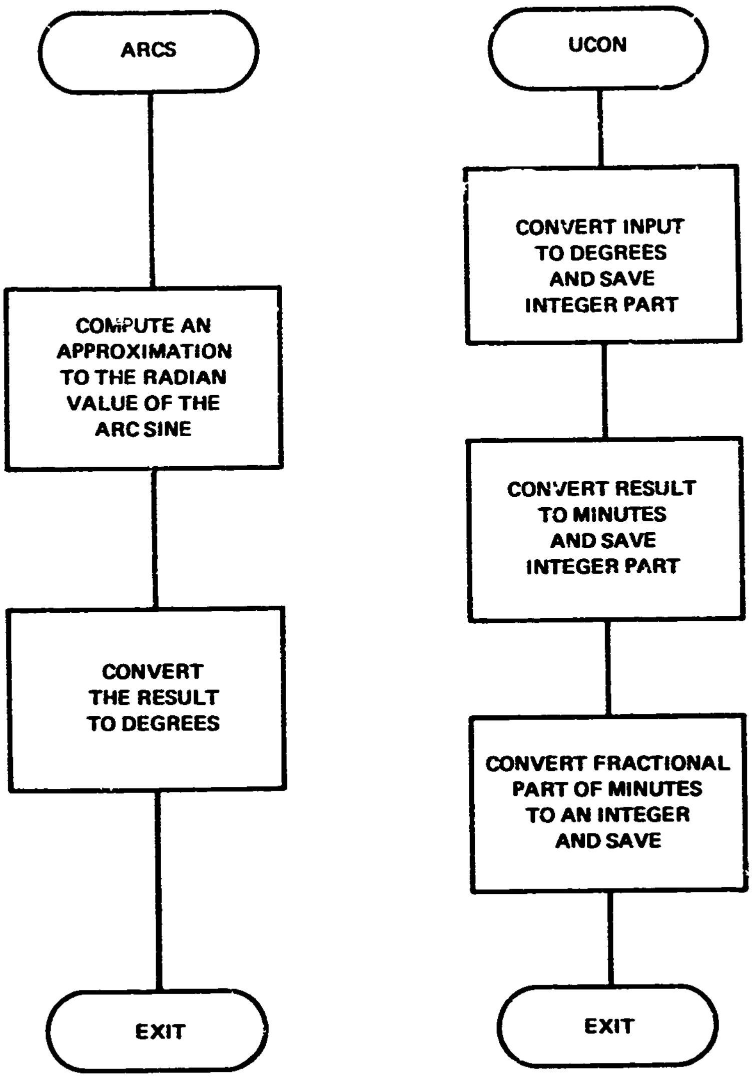

Fig. A-24 SUBROUTINE ARCS AND UCON

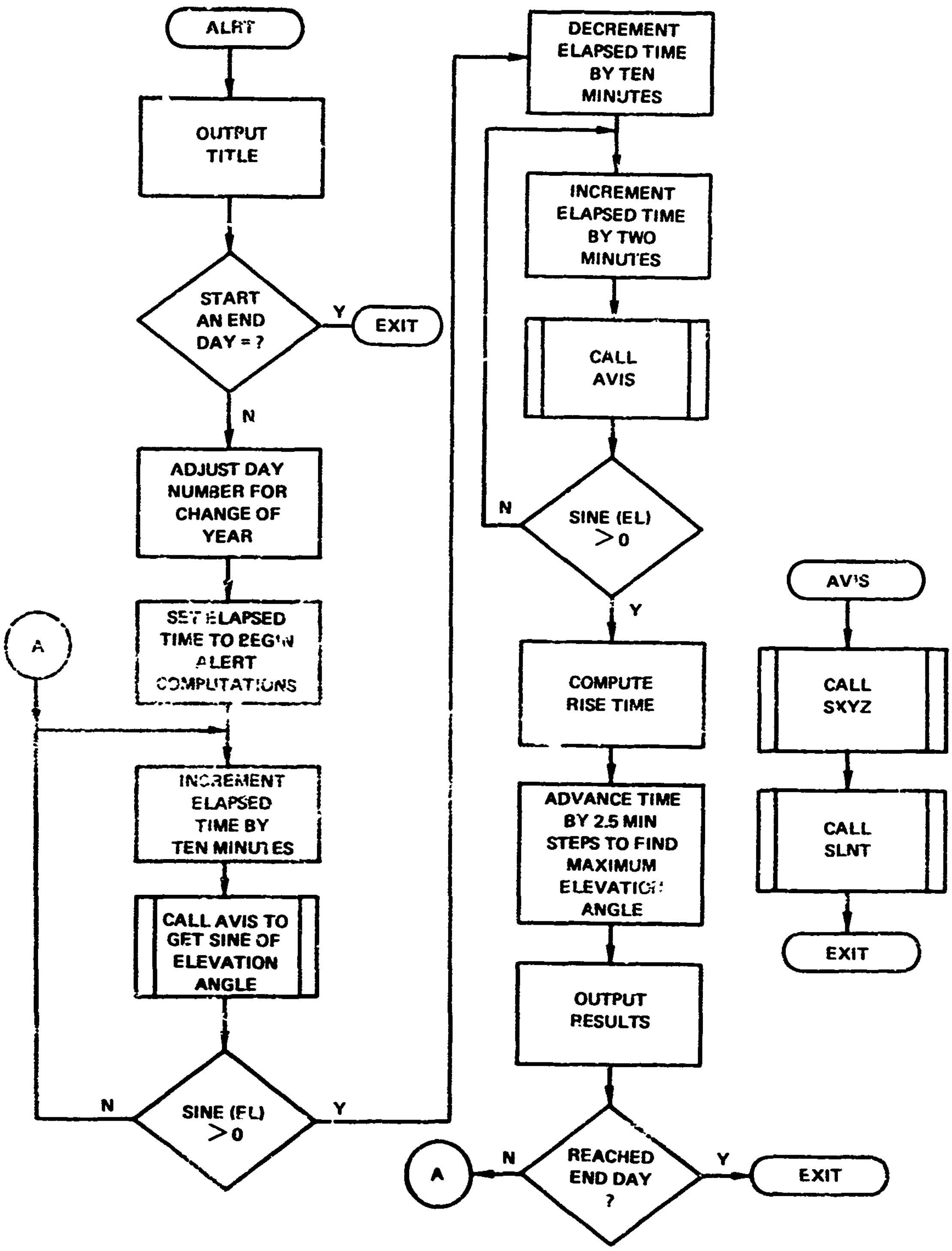

Fig. A-25 SUBROUTINES ALRT AND AVIS

APPENDIX B

FIXED POINT SCALING

The AN/SRN-9 navigation solution equations and the suggested fixed point scaling to be used in the solution are presented in this Appendix. It is assumed that a computer with at least 30-bit word length is available (i.e., sign and 29 bits) and that the error of arithmetic routines is in the 29th bit.

SCALING NOTATION

The register containing the word of interest is considered to have the most significant bit at the left and the least significant bit to the right. The decimal point is normally considered to be at the far left, between the sign bit and most significant data bit. This situation is represented by s0. The letter s is used to indicate a scaling number. If the decimal place is considered to be to the right n places, the scaling is indicated by sn. If the decimal point is considered to be to the left n places, the scaling is indicated by s-n. To scale the number 9 (for example) optimally it should be scaled s4.

$$9_{10} = 1001 \text{ binary}$$

represented in a 30-bit word as

```
bit position 30 29 28 27 26 25 .......
             S.  1  0  0  1. 0
            s0            s4
```

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The number 0.25 would be scaled s-1 optimally.

$0.25_{10} = 0.01$ binary

$$\underset{s0}{0} \; \underset{s-1}{.} \; \boxed{100---} = \underset{s-1}{S.} \; 1 \; 0 \; 0 \cdots -$$

In the navigation equations the scaling is written above the variable of concern. Sometimes a shift of the decimal point of the result of a computation is needed to match that of another computation. This is indicated by giving the scaling of the result of the operation with an arrow to the desired scaling.

Example:

$$x = a + by$$

suppose a is scaled s3

b is scaled s2

y is scaled s4

and it is desired to have x scaled s2. This would be indicated by:

$$x = \overset{s3}{a} + \underbrace{\overset{s2}{b}\,\overset{s4}{y}}_{s6 \rightarrow s3} \qquad s3 \longrightarrow s2$$

In multiplication, scaling numbers add. In division, scaling numbers are formed by subtracting the denominator scaling from the numerator scaling. In division, it is necessary to adjust the scaling before dividing so that the result of the division will have the proper scaling to insure no overflow (i.e., the answer will fit into the resulting scaling).

INPUTS AND UNITS

The inputs to the navigation computation and the units in which they are expressed are listed below.

Symbol	Units	Scaling
t_p	minutes	s11
n	radians/minute	s-3
ω_o	radians	s4
$\lvert\dot{\omega}\rvert$	radians/minute	s-11
ϵ	dimensionless	s-3
A_o	meters	s24
Ω_o	radians	s4
$\dot{\Omega}$	radians/minute	s-7
Ci	dimensionless	s-5
Λ_G	radians	s4
Si	dimensionless	s1
ΔE_k	radians	s-2
ΔA_k	meters	s24
ηk	meters	s9
t_o	minutes	s4
T_c	minutes	s11
N_k	cycles	s23
R_k	cycles	s12
φ_e	radians	s4
λe	radians	s4
φ_k	radians	s4
λ_k	radians	s4
$\bar{f}_o$	cycles/minute	s21
f	dimensionless	s6

Symbol	Units	Scaling
δ	dimensionless	s0
R_o	meters	s23
h'	meters	s23
ω_e	radians/minute	s-7
L_o	meters/cycle	s0
v	knots	s9
d	radians	s4

SCALING FOR NAVIGATION FIX SOLUTION AND ALERTS

STEP A – Correct 400-MHz doppler counts for effect of ionospheric refraction.

$$\text{If } N_{k_{400}} \leq 2 \times 10^6,\ N_k = 0, \text{ otherwise continue.} \tag{A.1}$$

$$\text{If } R_k = 2 \times 10^3,\ N_k = 0, \text{ otherwise continue.} \tag{A.2}$$

$$N_k = \overset{s23}{N_{k_{400}}} + \overset{s0}{\frac{24}{55}} \underbrace{\overset{s12}{(2000} - \overset{s12}{R_k)}}_{s12 \rightarrow s23} \quad \text{s23 cycles.} \tag{A.3}$$

STEP B – Compute navigator's relative motion in latitude and longitude.

$$\delta = f\ (2-f) \qquad \text{s0.} \tag{B.1}$$

$$\Delta\lambda_k = \overset{s4}{(k-1)}\ \overset{s9}{v}\ \underset{s1}{\overset{s1}{\frac{\sin d}{\cos\varphi_e}}} \left[\overset{s-13}{\frac{1}{3443.934}}\ \frac{2}{60}\right] \underline{\left[(1 - 0.5\ \overset{s1}{\delta}\ \sin^2\varphi_e)\right]}_{s1\rightarrow s2}\ s2 \text{ radians.} \quad (B.2)$$

$$\Delta\varphi_k = \overset{s4}{(k-1)}\ \overset{s9}{v}\ \overset{s1}{\cos d} \left[\frac{1^{s-13}}{3443.934}\ \frac{2}{60}\right]\left[1 + \delta\ \overset{s1}{(1-0.5\delta\ \sin^2\varphi_e}\right] s2 \text{ radians.} \quad (B.3)$$

STEP C – Compute first fiducial time.

$$K' = \overset{s11}{\left[\frac{T_c}{\underset{s2}{2}}\right]} \quad [\ ] \text{ means integer part of} \qquad s10 \text{ minutes.} \quad (C.1)$$

$$\underline{s9\rightarrow s10}$$

$$I = \overset{s2}{2}\ \overset{s10}{K'} \qquad \underline{s12\rightarrow s11} \qquad s11 \text{ minutes.} \quad (C.2)$$

$$T_c' = \left[\frac{\overset{s11}{I}}{\underset{s5}{30}}\right] \qquad s6 \text{ minutes.} \quad (C.3)$$

$$J = \overset{s11}{I} - \overset{s5}{30}\ \overset{s6}{T_c'} \qquad s11 \text{ minutes.} \quad (C.4)$$

$$s6 \rightarrow s11$$

$$H = \overset{s2}{2}\ \overset{s4}{t_0} - \overset{s11}{J} \qquad s11 \text{ minutes.} \quad (C.5)$$

$$T_0 = \overset{s11}{I} + \overset{s11}{H} - \overset{s5}{30}\left[\frac{\overset{s11}{H}}{\underset{s5}{15}}\right] \qquad s11 \text{ minutes.} \quad (C.6)$$

STEP D – Decode out-of-plane orbit corrections and interpolate for missing corrections.

$$N = T_0^{s11} - 4^{s3}\left[\frac{T_0}{4}\right]^{s11}_{s3} \quad [\,] \text{ means integer part of } s11 \text{ minutes.} \qquad (D.1)$$

Eqs. (D.3) through (D.5) shall be executed for

$$k = 2, 4, 6, \text{---} \text{ if } N = 0 \text{ or for } k = 1, 3, 5, \text{---} \text{ if } N \neq 0. \qquad (D.2)$$

If $\eta_k - 5 \geq 0$ then (D.3)

$CP(\ell) = 100(\eta_k - 5) + 10\,\eta_{k+1}$ s9

and $CPT(\ell) = k$. s5

If $\eta_k - 5 < 0$ and (D.4)

$\eta_k \neq 0$ then

$CP(\ell) = 100(\eta_k - 5) - 10\,\eta_{k+1}$ s9

and $CPT(\ell) = k$. s5

If $\eta_k - 5 < 0$ and (D.5)

$\eta_k = 0$ then

$CP(\ell) = -10\,\eta_{k+1}$ s9

and $CPT(\ell) = k$ s5

where $\ell = 1, 2, 3, \text{---}, OP$.

If OP $\leq$ 2 then (D. 6)

$$\eta_k = 0 \text{ for } k = 1, 2, 3, \cdots, KM.$$

If OP = 3, execute Eq. (D. 7-a) for k = 1, 2, 3, ---, KM.
If OP = 4 and N = 0 execute Eq. (D. 7-a) for
k = 1, 2, 3 and Eq. (D. 7-b) for k = 4, 5, 6, ---, KM.
If OP = 4 and N $\neq$ 0 execute Eq. (D. 7(a) for
k = 1, 2 and Eq. (D. 7-b) for k = 3. 4, 5, ---, KM. (D. 7)
If OP = 5 and N = 0 execute Eq. (D. 7-a) for
k = 1, 2, 3, Eq. (D. 7-b) for k = 4, 5, and
Eq. (D. 7-c) for k = 6, 7, 8, ---, KM.
If OP = 5 and N $\neq$ 0 execute Eq. (D. 7-a) for k =
1, 2, 3. Eq. (D. 7-b) for k = 4, and Eq. (D. 7-c) for
k = 5, 6, 7, ---, KM.

$$\eta_k = \underset{\underline{s10 \to s7}}{\left[\frac{\overset{s5}{(k+1)} - \overset{s5}{CPT(2)}}{\underset{s5}{CPT(1)} - \underset{s5}{CPT(2)}} \cdot \frac{\overset{s5}{(k+1)} - \overset{s5}{CPT(3)}}{\underset{s5}{CPT(1)} - \underset{s5}{CPT(3)}} \right]} \overset{s9}{CP(1)} \quad \underline{s12 \to s9} \; s9$$

$$+ \underset{\underline{s10 \to s7}}{\left[\frac{\overset{s5}{(k+1)} - \overset{s5}{CPT(1)}}{\underset{s5}{CPT(2)} - \underset{s5}{CPT(1)}} \cdot \frac{\overset{s5}{(k+1)} - \overset{s5}{CPT(3)}}{\underset{s5}{CPT(2)} - \underset{s5}{CPT(3)}} \right]} \overset{s9}{CP(2)} \quad \underline{s12 \to s9} \; s9 \qquad (D.\ 7\text{-}a)$$

$$+ \underset{\underline{s10 \to s7}}{\left[\frac{\overset{s5}{(k+1)} - \overset{s5}{CPT(1)}}{\underset{s5}{CPT(3)} - \underset{s5}{CPT(1)}} \cdot \frac{\overset{s5}{(k+1)} - \overset{s5}{CPT(2)}}{\underset{s5}{CPT(3)} - \underset{s5}{CPT(2)}} \right]} \overset{s9}{CP(3)} \quad \underline{s12 \to s9} \; s9.$$

$$\eta_k = \left[\frac{\overset{s5}{(k+1)} - \overset{s5}{CPT(3)}}{\underset{s5}{CPT(2)} - \underset{s5}{CPT(3)}} \cdot \frac{\overset{s5}{(k+1)} - \overset{s5}{CPT(4)}}{\underset{s5}{CPT(2)} - \underset{s5}{CPT(4)}} \right]_{\underline{s10-s7}}^{s9} CP(2) \quad \underline{s12-s9}\ s9$$

$$+ \left[\frac{\overset{s5}{(k+1)} - \overset{s5}{CPT(2)}}{\underset{s5}{CPT(3)} - \underset{s5}{CPT(2)}} \cdot \frac{\overset{s5}{(k+1)} - \overset{s5}{CPT(4)}}{\underset{s5}{CPT(3)} - \underset{s5}{CPT(4)}} \right]_{\underline{s10-s7}}^{s9} CP(3) \quad \underline{s12-s9}\ s9 \qquad \text{(D. 7-b)}$$

$$+ \left[\frac{\overset{s5}{(k+1)} - \overset{s5}{CPT(2)}}{\underset{s5}{CPT(4)} - \underset{s5}{CPT(2)}} \cdot \frac{\overset{s5}{(k+1)} - \overset{s5}{CPT(3)}}{\underset{s5}{CPT(4)} - \underset{s5}{CPT(3)}} \right]_{\underline{s10-s7}}^{s9} CP(4) \quad \underline{s12-s9}\ s9.$$

$$\eta_k = \left[\frac{\overset{s5}{(k+1)} - \overset{s5}{CPT(4)}}{\underset{s5}{CPT(3)} - \underset{s5}{CPT(4)}} \cdot \frac{\overset{s5}{(k+1)} - \overset{s5}{CPT(5)}}{\underset{s5}{CPT(3)} - \underset{s5}{CPT(5)}} \right]_{\underline{s10-s7}}^{s9} CP(3) \quad \underline{s12-s9}\ s9$$

$$+ \left[\frac{\overset{s5}{(k+1)} - \overset{s5}{CPT(3)}}{\underset{s5}{CPT(4)} - \underset{s5}{CPT(3)}} \cdot \frac{\overset{s5}{(k+1)} - \overset{s5}{CPT(5)}}{\underset{s5}{CPT(4)} - \underset{s5}{CPT(5)}} \right]_{\underline{s10-s7}}^{s9} CP(4) \quad \underline{s12-s9}\ s9 \qquad \text{(D. 7-c)}$$

$$+ \left[\frac{\overset{s5}{(k+1)} - \overset{s5}{CPT(3)}}{\underset{s5}{CPT(5)} - \underset{s5}{CPT(3)}} \cdot \frac{\overset{s5}{(k+1)} - \overset{s5}{CPT(4)}}{\underset{s5}{CPT(5)} - \underset{s5}{CPT(4)}} \right]_{s10-s7} CP(5) \quad \underline{s12-s9}\ s9 .$$

STEP E — Compute time between time of perigee and first fiducial time.

$$t = \overset{s11}{T_0} - \overset{s11}{t_p} \qquad \text{s11 minutes.} \qquad \text{(E.1)}$$

$$t_R = \overset{s11}{1440} - 2\overset{s4}{\Pi}/\underset{s-3}{n}\ \underline{s7 \rightarrow s11} \qquad \text{s11 minutes.} \qquad \text{(E.2)}$$

$$\left.\begin{array}{l} \text{If } t \le -480 \text{ then } \Delta t_p = \overset{s11}{t} + \overset{s11}{1440} \\ \text{If } -480 < t < t_R \text{ then } \Delta t_p = \overset{s11}{t} \\ \text{If } t_R \le t \text{ then } \Delta t_p = \overset{s11}{t} - \overset{s11}{1440} \end{array}\right\} \quad \text{s11 minutes.} \qquad \text{(E.3)}$$

STEP F — Compute satellite coordinates at 2-minute intervals.

$$\Delta t_k = \overset{s11}{\Delta t_p} + \overset{s11}{2\ (k-1)} \qquad \text{s11 minutes.} \qquad \text{(F.1)}$$

$$M_k = \overset{s-3}{n}\ \overset{s11}{\Delta t_k}\ \underline{s8 \rightarrow s7} \qquad \text{s7 radians.} \qquad \text{(F.2)}$$

$$E_K = \overset{s7}{M_k} + \underset{s-2 \rightarrow s7}{\left[\overset{s-3}{\epsilon} \sin \overset{s1}{M_k} + \overset{s-2}{\Delta E_k}\right]} \qquad \text{s7 radians.} \qquad \text{(F.3)}$$

$$A_k = \overset{s24}{A_0} + \overset{s24}{\Delta A_k} \qquad \text{s24 meters.} \qquad \text{(F.4)}$$

$$u_k = \underset{s25 \rightarrow s24}{\left[\overset{s24}{A_k}\ (\cos \overset{s1}{E_k} - \overset{\underline{s-3 \rightarrow s1}}{\epsilon})\right]} \qquad \text{s24 meters.} \qquad \text{(F.5)}$$

$$v_k = \overset{s24}{A_k} \; \overset{s1}{(\sin E_k)} \quad s25 \rightarrow s24 \qquad s24 \text{ meters.} \qquad (F.6)$$

$$\omega_k = \overset{s4}{\omega_0} - \left[\begin{matrix} s\text{-}11 s11 \\ \dot{\omega} \Delta t_k \end{matrix}\right] s0 \rightarrow s4 \qquad s4 \text{ radians.} \qquad (F.7)$$

$$x'_k = \overset{s24}{u_k} \; \overset{s1}{\cos \omega_k} - \overset{s24}{v_k} \; \underset{s25 \rightarrow s24}{\overset{s1}{\sin \omega_k}} \qquad s24 \text{ meters.} \qquad (F.8)$$

$$y'_k = \overset{s24}{u_k} \; \overset{s1}{\sin \omega_k} + \overset{s24}{v_k} \; \overset{s1}{\cos \omega_k} \qquad s25 \text{ meters.} \qquad (F.9)$$

$$z' = \overset{s9}{\eta_k} \qquad s9 \text{ meters.} \qquad (F.10)$$

$$\beta_k = (\overset{s4}{\Omega_0} - \overset{s4}{\Lambda_G}) + (\overset{s^{-7}}{\dot{\Omega}} - \overset{s_{-7}}{\omega_e}) \overset{s11}{\Delta t_k} \qquad s4 \text{ radians.} \qquad (F.11)$$

$$X_{Sk} = \underset{s25 \rightarrow s24}{\left[\begin{matrix} s24 & s1 \\ x'_k & \cos \beta_k \end{matrix}\right]} - \underset{s21 \rightarrow s24}{\left[\begin{matrix} s25 & s\text{-}5 & s1 \\ y'_k & Ci & \sin \beta_k \end{matrix}\right]} \qquad (F.12)$$

$$+ \underset{s11 \rightarrow s24}{\left[\begin{matrix} s9 & s1 & s1 \\ z'_k & Si & \sin \beta_k \end{matrix}\right]} \qquad s24 \text{ meters.}$$

$$Y_{Sk} = \underset{s25 \rightarrow s24}{\left[\begin{matrix} s24 & s1 \\ x'_k & \sin \beta_k \end{matrix}\right]} + \underset{s21 \rightarrow s24}{\left[\begin{matrix} s25 & s\text{-}5 & s1 \\ y'_k & Ci & \cos \beta_k \end{matrix}\right]} \qquad (F.13)$$

$$- \underset{s11 \rightarrow s24}{\left[\begin{matrix} s9 & s1 & s1 \\ z'_k & Si & \cos \beta_k \end{matrix}\right]} \qquad s24 \text{ meters.}$$

$$Z_{Sk} = \overset{s25}{y'_k}\ \overset{s1}{Si} + \underset{s4 \rightarrow s26}{\left[\overset{s9}{z'_k}\ \overset{s-5}{Ci}\right]_{s26 \rightarrow s24}} \qquad s24 \text{ meters.} \qquad (F.14)$$

STEP G – Compute navigator's coordinates and partial derivatives.

$$\cos \varphi_k = \cos (\varphi_f + \Delta\varphi_k) \qquad s1. \qquad (G.1)$$

$$\sin \varphi_k = \sin (\varphi_f + \Delta\varphi_k) \qquad s1. \qquad (G.2)$$

$$\cos \lambda_k = \cos (\lambda_f + \Delta\lambda_k) \qquad s1. \qquad (G.3)$$

$$\sin \lambda_k = \sin (\lambda_f + \Delta\lambda_k) \qquad s1. \qquad (G.4)$$

$$D_k^{\,2} = \overset{s46}{R_0^{\,2}} \left[\overset{s2}{\cos^2 \varphi_k} + \underset{s48 \rightarrow s46}{\overset{s0}{(1-f)^2}\overset{s2}{\sin^2 \varphi_k}}\right] \quad s46 \text{ (meters)}^2. \qquad (G.5)$$

$$X_{Nk} = \left[(\overset{s46}{R_0^{\,2}} / \underset{s23}{D_k}) + h'\right]^{s23} \underset{s25 \rightarrow s24}{\overset{s1}{\cos \varphi_k}\ \overset{s1}{\cos \lambda_k}} \quad s24 \text{ meters.} \qquad (G.6)$$

$$Y_{Nk} = \left[(\overset{s46}{R_0^{\,2}} / \underset{s23}{D_k} + h'\right]^{s23} \underset{s25 \rightarrow s24}{\overset{s1}{\cos \varphi_k}\ \overset{s1}{\sin \lambda_k}} \quad s24 \text{ meters.} \qquad (G.7)$$

$$Z_{Nk} = \left[\frac{\overset{s46}{R_0^{\,2}}\ \overset{s0}{(1-f)^2}}{\underset{s23}{D_k}} + h'\right]^{s23} \overset{s1}{\sin \varphi_k} \qquad s24 \text{ meters.} \qquad (G.8)$$

$$\frac{\partial X_{Nk}}{\partial \varphi} = -\underset{s25 \rightarrow s23}{\underline{\left[\frac{\overset{s92}{R_0^{\,4}}\ \overset{s0}{(1-f)^2}}{\underset{s69}{D_k^{\,3}}} + \overset{s23}{h'}\right] \overset{s1}{\sin\varphi}\ \overset{s1}{\cos\lambda_k}}} \qquad \text{s23 meters/ radian} \qquad (G.9)$$

$$\frac{\partial Y_{Nk}}{\partial \varphi} = -\underset{s25 \rightarrow s23}{\underline{\left[\frac{\overset{s92}{R_0^{\,4}}\overset{s0}{(1-f)^2}}{\underset{s69}{D_k^{\,3}}} + \overset{s23}{h'}\right] \overset{s1}{\sin\varphi_k}\ \overset{s1}{\sin\lambda_k}}} \qquad \text{s23 meters/ radian} \qquad (G.10)$$

$$\frac{\partial Z_{Nk}}{\partial \varphi} = \underset{s24 \rightarrow s23}{\underline{\left[\frac{\overset{s92}{R_0^{\,4}}\overset{s0}{(1-f)^2}}{\underset{s69}{D_k^{\,3}}} + \overset{s23}{h'}\right] \cos\varphi_k}} \qquad \text{s23 meters/ radian} \qquad (G.11)$$

$$\frac{\partial X_{Nk}}{\partial \lambda} = -\overset{s24}{Y_{Nk}} \qquad \text{s24 meters/ radian} \qquad (G.12)$$

$$\frac{\partial Y_{Nk}}{\partial \lambda} = \overset{s24}{X_{Nk}} \qquad \text{s24 meters/ radian} \qquad (G.13)$$

<u>STEP H</u> – Compute theoretical slant range differences, partial derivatives, and elevation angle.

$$X_k = \overset{s24}{X_{Sk}} - \overset{s24}{X_{Nk}} \qquad \text{s24 meters.} \qquad (H.1)$$

$$Y_k = \overset{s24}{Y_{Sk}} - \overset{s24}{Y_{Nk}} \qquad \text{s24 meters.} \qquad (H.2)$$

$$Z_k = \overset{s24}{Z_{Sk}} - \overset{s24}{Z_{Nk}} \qquad \text{s24 meters.} \qquad \text{(H. 3)}$$

$$S_k^{\ 2} = \overset{s48}{X_k^{\ 2}} + \overset{s48}{Y_k^{\ 2}} + \overset{s48}{Z_k^{\ 2}} \qquad \text{s48 (meters)}^2. \qquad \text{(H. 4)}$$

$$S_k = \left[\overset{s48}{X_k^{\ 2}} + \overset{s48}{Y_k^{\ 2}} + \overset{s48}{Z_k^{\ 2}} \right]^{1/2} \qquad \text{s24 meters.} \qquad \text{(H. 5)}$$

$$R_k^{\ 2} = \overset{s48}{X_{Sk}^{\ 2}} + \overset{s48}{Y_{Sk}^{\ 2}} + \overset{s48}{Z_{Sk}^{\ 2}} \qquad \text{s48 (meters)}^2. \qquad \text{(H. 6)}$$

$$r_k^{\ 2} = \overset{s48}{X_{Nk}^{\ 2}} + \overset{s48}{Y_{Nk}^{\ 2}} + \overset{s48}{Z_{Nk}^{\ 2}} \qquad \text{s48 (meters)}^2. \qquad \text{(H. 7)}$$

$$r_k = \left[\overset{s48}{X_{Nk}^{\ 2}} + \overset{s48}{Y_{Nk}^{\ 2}} + \overset{s48}{Z_{Nk}^{\ 2}} \right]^{1/2}_{s24 \to s23} \qquad \text{s23 meters} \qquad \text{(H. 8)}$$

$$\frac{\partial S_k}{\partial \varphi} = \frac{-1}{\underset{s24}{S_k}} \left[\overset{s24}{X_k} \overset{s23}{\frac{\partial X_{Nk}}{\partial \varphi}} + \overset{s24}{Y_k} \overset{s23}{\frac{\partial Y_{Nk}}{\partial \varphi}} + \overset{s24}{Z_k} \overset{s23}{\frac{\partial Z_{Nk}}{\partial \varphi}} \right] \qquad \text{(H. 9)}$$

s23 meters/
radian.

$$\frac{\partial S_k}{\partial \lambda} = \frac{-1}{\underset{s24}{S_k}} \left[\overset{s24}{X_k} \overset{s24}{\frac{\partial X_{Nk}}{\partial \lambda}} + \overset{s24}{Y_k} \overset{s24}{\frac{\partial Y_{Nk}}{\partial \lambda}} \right] \qquad \text{s24 meters/ radian.} \qquad \text{(H. 10)}$$

$$\sin E_k = \left[\frac{\overset{s24}{X_k}\ \overset{s24}{X_{Nk}} + \overset{s24}{Y_k}\ \overset{s24}{Y_{Nk}} + \overset{s24}{Z_k}\ Z_{Nk}}{\underset{s24}{S_k}\ \underset{s23}{r_k}} \right] \qquad \text{s1.} \qquad \text{(H. 11)}$$

$$\text{If } \sin E_{k+1} < \sin E_k \text{ then } \sin E_{max} = \sin E_k. \qquad \text{(H. 12)}$$

STEP I – Compute refraction corrected measured slant range differences.

$$\hat{S}_{ko} = \overset{s23}{N_k}\ \overset{s0}{L_o} - \overset{s2}{2.0}\ \overset{s21}{\bar{f}_o}\ \overset{s0}{L_o} \qquad \text{s23 meters.} \qquad \text{(I. 1)}$$

STEP J – Form the C matrix.

$$C_{J0} = -\ \overset{s23}{\hat{S}_{ko}} + \underbrace{\left[\overset{s23}{S_{k+1}} - \overset{s23}{S_{k+1}}\right]}_{s23 \rightarrow s20} \qquad \text{s20 meters.} \qquad \text{(J. 1)}$$

$$C_{J1} = -\underbrace{\left[\overset{s2}{2.0}\ \overset{s0}{L_o}\right]}_{s2 \rightarrow s1} \qquad \text{s1}\ \frac{\text{meters-minutes}}{\text{cycle}} \qquad \text{(J. 2)}$$

$$C_{J2} = -\ \frac{\partial \overset{s23}{S_{k+1}}}{\partial \varphi} + \frac{\partial \overset{s23}{S_k}}{\partial \varphi} \qquad \text{s23 meters/radian.} \qquad \text{(J. 3)}$$

$$C_{J3} = \underbrace{\left[-\ \frac{\partial \overset{s24}{S_{k+1}}}{\lambda} + \frac{\partial \overset{s24}{S_k}}{\partial \lambda}\right]}_{s24 \rightarrow s23} \qquad \text{s23 meters/radian.} \qquad \text{(J. 4)}$$

STEP K – Form the A matrix.

J - Number of rows in C matrix.

$$a_{10} = \sum_{m=1}^{J} \overset{s1}{C_{m1}}\ \overset{s20}{C_{m0}} \quad \underline{s21 \rightarrow s23} \quad \text{s23.} \qquad \text{(K. 1)}$$

$$a_{20} = \sum_{m=1}^{J} \overset{s23}{C_{m2}}\ \overset{s20}{C_{m0}} \quad \underline{s43 \rightarrow s45} \quad \text{s45.} \qquad \text{(K. 2)}$$

$$a_{30} = \sum_{m=1}^{J} C_{m3}^{s23} C_{m0}^{s20} \; \underline{s43 \rightarrow s42} \quad s42. \tag{K. 3}$$

$$a_{11} = \sum_{m=1}^{J} C_{m1}^{s1} C_{m1}^{s1} \; \underline{s2 \rightarrow s5} \quad s5. \tag{K. 4}$$

$$a_{21} = \sum_{m=1}^{J} C_{m2}^{s23} C_{m1}^{s1} \; \underline{s24 \rightarrow s27} \quad s27. \tag{K. 5}$$

$$a_{31} = \sum_{m=1}^{J} C_{m3}^{s23} C_{m1}^{s1} \; \underline{s24 \rightarrow s23} \quad s23. \tag{K. 6}$$

$$a_{12} = a_{21}. \tag{K. 7}$$

$$a_{22} = \sum_{m=1}^{J} C_{m2}^{s23} C_{m2}^{s23} \; \underline{s46 \rightarrow s49} \quad s49. \tag{K. 8}$$

$$a_{32} = \sum_{m=1}^{J} C_{m3}^{s23} C_{m2}^{s23} \; \underline{s46 \rightarrow s45} \quad s45. \tag{K. 9}$$

$$a_{13} = a_{31}. \tag{K. 10}$$

$$a_{23} = a_{32}. \tag{K. 11}$$

$$a_{33} = \sum_{m=1}^{J} C_{m3}^{s23} C_{m3}^{s23} \; \underline{s46 \rightarrow s43} \quad s43. \tag{K. 12}$$

<u>STEP L</u> – Solve for Δf, $\Delta\varphi$, $\Delta\lambda$ and update estimates of f, φ, and λ.

$$B11 = \overset{s49}{a_{22}} - \overset{s27}{a_{12}} \; \underset{s5}{\frac{\overset{s27}{a_{12}}}{a_{11}}} \qquad s49. \qquad (L.1)$$

$$B12 = \overset{s45}{a_{23}} - \overset{s23}{a_{13}} \; \underset{s5}{\frac{\overset{s27}{a_{12}}}{a_{11}}} \qquad s45. \qquad (L.2)$$

$$B10 = \overset{s45}{a_{20}} - \overset{s23}{a_{10}} \; \underset{s5}{\frac{\overset{s27}{a_{12}}}{a_{11}}} \qquad s45. \qquad (L.3)$$

$$B22 = \overset{s43}{a_{33}} - \underset{\underline{s41 \to s43}}{\left[\overset{s23}{a_{13}} \; \underset{s5}{\frac{\overset{s23}{a_{13}}}{a_{11}}} \right]} \qquad s43. \qquad (L.4)$$

$$B20 = \overset{s42}{a_{30}} - \underset{\underline{s41 \to s42}}{\left[\overset{s23}{a_{10}} \; \underset{s5}{\frac{\overset{s23}{a_{13}}}{a_{11}}} \right]} \qquad s42. \qquad (L.5)$$

$$\Delta = \underset{s88 \to s87}{\left(\underset{s92 \to s91}{\left[\overset{s49}{B11} \; \overset{s43}{B22} \right]} - \underset{s90 \to s91}{\left[\overset{s45}{B12} \; \overset{s45}{B12} \right]} \right)} \qquad s91. \qquad (L.6)$$

$$\Delta\varphi = \frac{(\overset{s43}{B22} \; \overset{s45}{B10} - \overset{s45}{B12} \; \overset{s42}{B20})}{\underset{s91}{\Delta}} \qquad s\text{-}4 \text{ radians.} \qquad (L.7)$$

$$\Delta\lambda = \frac{\overset{s91 \to s90}{(\overset{s49}{B11} \; \overset{s42}{B20}} - \overset{s45}{B12} \; \overset{s45}{B10})}{\underset{s91}{\Delta}} \qquad s\text{-}1 \text{ radian.} \qquad (L.8)$$

$$\Delta f = \frac{\overset{s23}{a_{10}} - \overset{s27}{(a_{12})}\,\overset{s-4}{(\Delta\varphi)} - \overset{\frac{s22\rightarrow s23}{s23}}{(a_{13})}\,\overset{s-1}{(\Delta\lambda)}}{\underset{s5}{a_{11}}} \qquad \text{s18 cycles/minute.} \qquad \text{(L. 9)}$$

$$\overset{s21}{f} = f + \overset{s18\rightarrow s21}{\Delta f} \text{ where } f = \bar{f}_o \text{ on first iteration} \qquad \text{s21 cycles/minute.} \qquad \text{(L. 10)}$$

$$\varphi_f = \overset{s4}{\varphi_f} + \overset{s-4\rightarrow s4}{\Delta\varphi} \qquad \text{s4 radian.} \qquad \text{(L. 11)}$$

$$\lambda_f = \overset{s4}{\lambda_f} + \overset{s-1\rightarrow s4}{\Delta\lambda} \qquad \text{s4 radian.} \qquad \text{(L. 12)}$$

<u>STEP M</u> – Write out results.

$$DLA = \overset{s4}{\varphi_f} - \overset{s4}{\varphi_e} \qquad \text{s4 radians.} \qquad \text{(M. 1)}$$

$$DLO = \overset{s4}{\lambda_f} - \overset{s4}{\lambda_e} \qquad \text{s4 radians.} \qquad \text{(M. 2)}$$

$$FRQ = \overset{s21}{f} - \overset{s21}{\bar{f}_o} \qquad \text{s21 cycles/minute.} \qquad \text{(M. 3)}$$

$$TIME = \overset{s11}{T_0} + \overset{s3\rightarrow s11}{4} \qquad \text{s11 minutes.} \qquad \text{(M. 4)}$$

<u>STEP N</u> – Test for convergence.

If $\Delta f > 2.4$ cycle/minute

or if $\Delta\varphi > 1.2 \times 10^{-7}$ radian

or $\quad$ if $\Delta\lambda > \dfrac{1.2 \times 10^{-7}}{\cos \varphi_f}$ radian

and if ITER $<$ 10 then return to Step G. Otherwise go to Step O to edit doppler data or Step P to compute alerts.

STEP O – Edit doppler data.

If $\sin E_{KM-k+1} \leq \sin 7.5°$ and $\quad$ (O.1)

$\sin E_{KM-k+1} \leq \sin E_k$ and

$N_{KM-k} > 0$ then

$N_{KM-k} = 0$ and

$NDOP = NDOP - 1.$

Or if $\sin E_{KM-k+1} > \sin 7.5°$ and $\quad$ (O.2)

$\sin E_k \leq \sin 7.5°$ and

$N_{k+1} > 0$ then

$N_{k+1} = 0$ and

$NDOP = NDOP - 1.$

Otherwise make no changes in the N_k table.

STEP P – Compute alerts.

ISTP = MDAY-IDAY. If ISTP $<$ 0, let ISTP = ISTP + 365. $\quad$ (P.1)

Let $T_0 = T_0 - 18$, KM = 1, DE(K) = 0, DA(K) = 0, DN(K) = 0, I = 1, 2, 3, ---, ISTP, KDAY = I + IDAY. (P. 2)

Execute Steps F, G, and H. (P. 3)

If $E_k \leq 0$ let $T_0 = T_0 + 10$, and repeat Step P. 3 increasing T_0 by 10 each repetition until $E_k > 0$. (P. 4)

When $E_k > 0$ let $T_0 = T_0 - 10$, repeat Step P. 3, and then execute Step P. 6. (P. 5)

If $E_k \leq 0$, let $T_0 = T_0 + 2$, repeat Step P. 3 increasing T_0 by 2 each time until $E_k \geq 0$, and then execute Step P. 7. (P. 6)

When $E_k \geq 0$ let $T_0 - 2$ = RISE, $E_k = E_A$, $T_0 = T_0 + 0.25$ and repeat Step P. 3 increasing T_0 by 0.25 and letting the new value of $E_k = E_A$ each time until $E_k < E_A$. Then E_A = maximum elevation for that pass. (P. 7)

Write out day number of alert day, RISE time (hours and minutes), and maximum elevation angle for the alert pass. (P. 8)

Let $T_0 = T_0 + 10$ then repeat Steps P. 3 through P. 8 incrementing I and K until I > ISTP indicating that all alerts through the end of MDAY have been obtained. (P. 9)

Appendix C

FOUR-VARIABLE (VELOCITY NORTH) NAVIGATION

Section 7 does not include equations to solve for velocity north or equations for relative motion inputs other than those obtained from an inertial system (i.e., latitude and longitude) or a system providing course and speed data. This Appendix provides these equations and also presents a method of assigning numbers to satellite 2-minute messages when a real-time clock is not available. This method may be used to determine missing messages due to loss of lock.

EQUATIONS FOR SHIP'S MOTION FOR CONSTANT VELOCITY OR DISTANCE TRAVELED

A table of navigator's latitudes (φ_k) and navigator's longitudes (λ_k) is assumed available from Step B of Section 7. These table values may be provided by an inertial system or from calculations based on a knowledge of course and speed. However, there are situations where these types of data are not present and therefore these tables may also be constructed from information on either the navigator's velocity (north and east) or from distance traveled using certain approximations. No study has been done on the effects of these approximations. However, for the relatively small velocities encountered in shipboard navigation their effects are negligible.

Equations for Constant Velocity North and East

$$\varphi_k = \varphi_j + 2 \frac{(k-j) V_N}{R_0} [(1 + \delta (1 - 0.5\delta \sin^2\varphi_j)]$$

$$\lambda_k = \lambda_j + 2 \frac{(k-j) V_E}{R_0} \left(\frac{1 - 0.5\delta \sin^2\varphi_j}{\cos\varphi_j}\right)$$

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$\delta = f(2-f)$.

f = the value given in the table of program constants.

φ_j = and λ_j are initial estimates for the position at time t_j.

j is the value $k = 3$.

V_N and V_E are the constant north and east components of ship's velocity given in nautical miles per minute. R_o = 3443.934 nautical miles.

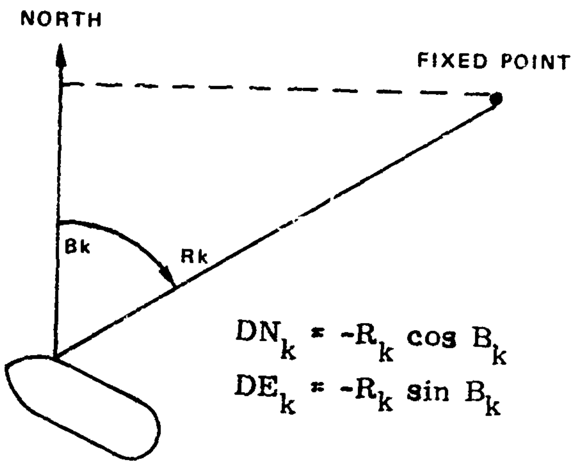
The factor of 2 appears because the fiducial time points denoted by k are 2 minutes apart. The approximations are caused by assuming that $\dot{\varphi}$ and $\dot{\lambda}$ are constant velocity north and east and ignoring changes in the earth radius during the time of the pass.

Equations for Distance Traveled

$$\varphi_k = \varphi_j + \frac{DN_k - DN_j}{R_0} \left[1 + \delta \left(1 - 0.5\delta \sin^2 \varphi_j\right)\right]$$

$$\lambda_k = \lambda_j + \frac{DE_k - DE_j}{R_0} \left[\frac{1 - 0.5\delta \sin^2 \varphi_j}{\cos \varphi_j}\right]$$

DN_k and DE_k are measured from any fixed arbitrary point. These distances may be obtained from a DRT plot, or as the range (R_k) and bearing (B_k) to a fixed point, as follows:



Additions to Section 7 to Solve for Velocity North Error

STEP G

Replace φ_k by $\varphi_k + 2\ \dot{\phi}_j\,(k-j)$ in Eqs. (G. 5) through (G. 11) where j is the value k = 3.

Additional Input: Estimate of velocity north (V_N) to get estimate of

$$\dot{\phi}_j = \frac{V_N\ \text{(knots)}}{3443.\times 60} = \frac{\text{rad}}{\text{min}}$$

$$\frac{\partial X_{Nk}}{\partial \dot{\varphi}_j} = 2\,(k-j)\,\frac{\partial X_{Nk}}{\partial \varphi} = \frac{\partial \varphi_k}{\partial \varphi_j}\,\frac{\partial X_{Nk}}{\partial \varphi_k} \qquad \text{(G. 14)}$$

$$\frac{\partial Y_{Nk}}{\partial \dot{\varphi}_j} = 2\,(k-j)\,\frac{\partial Y_{Nk}}{\partial \varphi} \qquad \text{(G. 15)}$$

$$\frac{\partial Z_{Nk}}{\partial \dot{\varphi}_j} = 2\,(k-j)\,\frac{\partial Z_{Nk}}{\partial \varphi} \qquad \text{(G. 16)}$$

These steps are not necessary in the computation but are included for background.

STEP H

$$\frac{\partial S_k}{\partial \dot{\varphi}_j} = 2\,(k-j)\,\frac{\partial S_k}{\partial \varphi}\,. \tag{H.13}$$

STEP J

$$C_{J4} = \frac{-\partial S_{k+1}}{\partial \dot{\varphi}_j} + \frac{\partial S_k}{\partial \dot{\varphi}_j}\,. \tag{J.5}$$

OUTPUT: The C matrix for velocity north

$$\begin{bmatrix} C_{10} & C_{11} & C_{12} & C_{13} & C_{14} \\ C_{20} & C_{21} & C_{22} & C_{23} & C_{24} \\ \cdot & \cdot & & \cdot & \cdot \\ \cdot & \cdot & \cdot & \cdot & \cdot \\ \cdot & \cdot & \cdot & \cdot & \cdot \\ \cdot & \cdot & \cdot & \cdot & \cdot \\ C_{J0} & C_{J1} & C_{J2} & C_{J3} & C_{J4} \end{bmatrix}$$

STEP K

$$a_{40} = \sum_{m=1}^{J} C_{m4}\; C_{m0}\,. \tag{K.3.1}$$

$$a_{41} = \sum_{m=1}^{J} C_{m4}\; C_{m1}\,. \tag{K.6.1}$$

$$a_{42} = \sum_{m=1}^{J} C_{m4}\; C_{m2}\,. \tag{K.9.1}$$

$$a_{43} = \sum_{m=1}^{J} C_{m4} \; C_{m3}. \qquad \text{(K. 12. 1)}$$

$$a_{14} = a_{41}. \qquad \text{(K. 12. 2)}$$

$$a_{24} = a_{42}. \qquad \text{(K. 12. 3)}$$

$$a_{34} = a_{43}. \qquad \text{(K. 12. 4)}$$

$$a_{44} = \sum_{m=1}^{J} C_{m4} \; C_{m4}. \qquad \text{(K. 12. 5)}$$

OUTPUT: A Matrix

$$-a_{10} + a_{11} \Delta f + a_{12} \Delta\varphi + a_{13} \Delta\lambda + a_{14} \Delta\gamma = 0$$
$$-a_{20} + a_{21} \Delta f + a_{22} \Delta\varphi + a_{23} \Delta\lambda + a_{24} \Delta\gamma = 0$$
$$-a_{30} + a_{31} \Delta f + a_{32} \Delta\varphi + a_{33} \Delta\lambda + a_{34} \Delta\gamma = 0$$
$$-a_{40} + a_{41} \Delta f + a_{42} \Delta\varphi + a_{43} \Delta\lambda + a_{44} \Delta\gamma = 0$$

STEP L

$$\Delta\gamma = \frac{a_{40} - \left[a_{41} \Delta f + a_{42} \Delta\varphi + a_{43} \Delta\lambda\right]}{a_{44}} \qquad \text{(L. 0)}$$

Eliminate $\Delta\gamma$ by redefining the A matrix at the end of Step K and used in Step L.

$$i = 1, 2, 3$$

$$a_{i0} = a_{i0} - \frac{a_{40}}{a_{44}} a_{i4} \qquad a_{i2} = a_{i2} - \frac{a_{42}}{a_{44}} a_{i4}$$

$$a_{i1} = a_{i1} - \frac{a_{41}}{a_{44}} a_{i4} \qquad a_{i3} = a_{i3} - \frac{a_{43}}{a_{44}} a_{i4} .$$

Solve for $\Delta\varphi$, $\Delta\lambda$, Δf as in Steps (L. 1) to (L. 9).

Then solve

$\Delta\gamma$ from (L. 0), (L. 9), (L. 7), (L. 8)

$$\dot{\Phi}_j = \dot{\varphi}_j + \Delta\gamma . \tag{L. 13}$$

STEP N

$$\text{If } |\Delta\gamma| > \frac{0.02}{3443. \times 60.} \quad \text{continue iterating at Step G} \tag{N. 2}$$

after convergence

$$V_N = 3443.934 \left(\cos^2 \varphi_j + (1-f)^2 \sin^2 \varphi_j\right)^{1/2} \dot{\Phi}_j \times 60.$$

Programming Method

Figure C-1 is a flow chart of a direct search method for implementing the velocity north solution. In this method the 3 x 3 solution is obtained together with the value of the sum of the square of the residual between the theoretical and measured slant range difference. The value for velocity north is increased from an initial value of zero by an amount Δv, a new fix solution obtained, and a new value calculated for the sum of the residuals. The process is repeated with

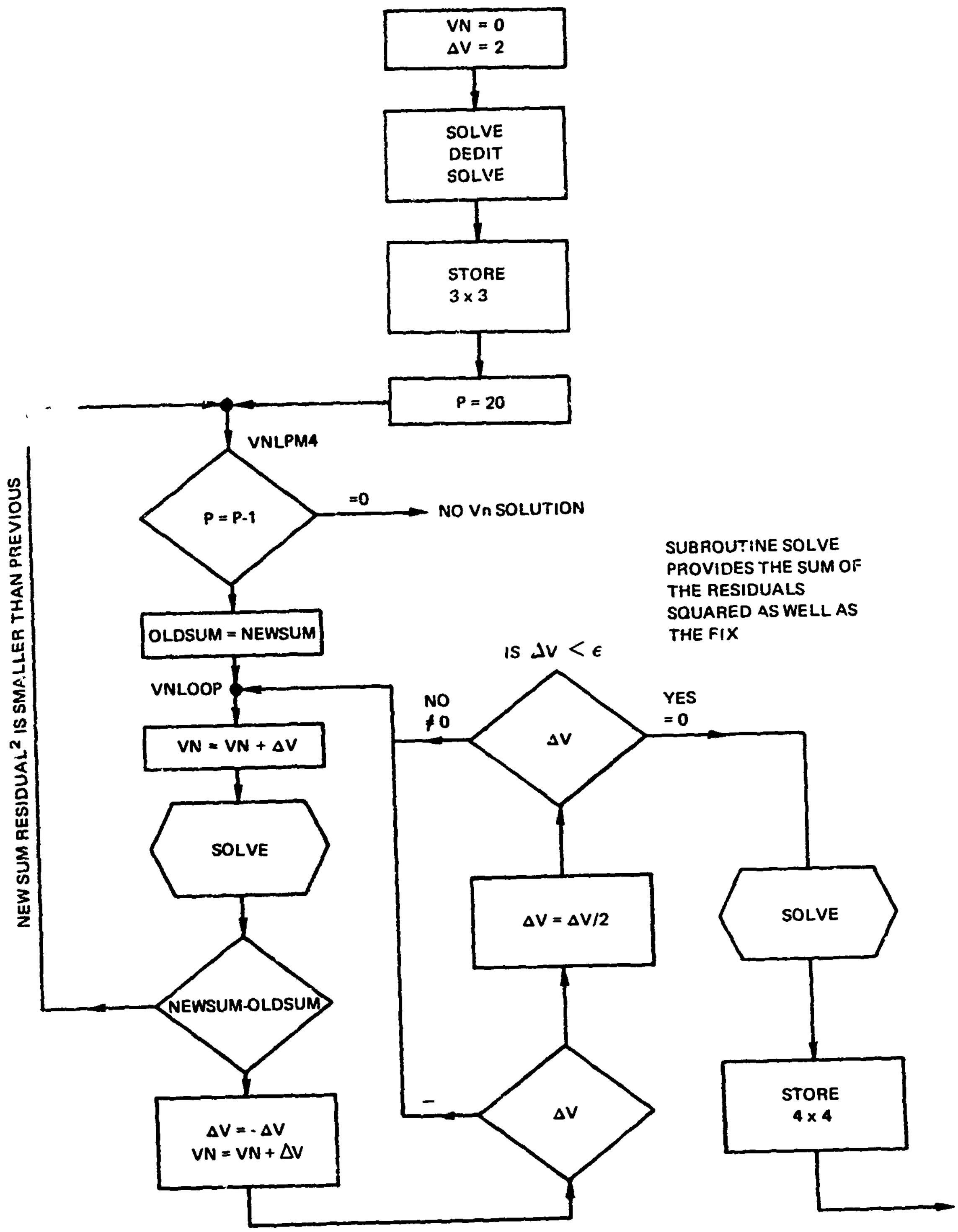


Fig. C-1 VELOCITY NORTH SOLUTION BY DIRECT SEARCH

Δv being incremented so long as the residuals continue to decline in value. The method provides for both positive and negative values of Δv.

NUMBER ASSIGNMENT TO SATELLITE 2-MINUTE MESSAGES TO DETERMINE MISSING MESSAGES

In order to majority vote the words from the satellite messages, it is necessary to keep track of which words represent the same parameter. The words which represent constant parameters do not change their position in the satellite message. However, words which represent the time varying parameters do change their position from one 2-minute message to the next. Whenever 2-minute messages are missing due to loss of lock it is necessary to know how many are missing. Otherwise the relative position of similar words will not be known between any two messages. Keeping track of missing messages is easy when messages are stored according to a clock. However, when a clock is not available some other means of determining missing messages must be used. The satellite data may be used to assign numbers to each message using the technique discussed later. These numbers are sequential with missing numbers for missing messages and therefore they accomplish the purpose of determining missing messages. Once this is done, majority voting of the time-varying words may be accomplished. From these results and an estimate of time (correct to 14 minutes) the correct time of the first doppler interval is calculated. The doppler counts stored during the pass may now be associated with the correct time interval by use of the message number assignments.

The time-varying words have contained within them a time integer modulo 15 that represents the time in some half hour for which that particular correction is to be applied. These time integers are sequential from 0 to 14 as time goes from 0 to 30 minutes. Each message contains eight sequential time varying words (see Fig. 10 and Table 1). These time integers could be used directly to assign message numbers. However, there is no assurance

that they are correct because of noise in transmission or receiving. The following technique is used to assign numbers to the messages and will work when the bit error rate is less than or equal to 1 out of 8, which is much higher than normally encountered.

Procedure

Strip off the least significant time digit (4 bits) from each of the eight time-varying words in the message of interest. This sequence of eight numbers may have errors, but it will be a subset of the sequence:

0123456789012340123456.

This eight-digit (32-bit) sequence is compared to a known, error-free sequence. The known sequence is shifted a digit at a time until the number of bit errors between the two sequences is less than five. The number of shifts required to do this is the number assigned to that message.

Table C-1 shows the number of bit errors between any two (BCDX3) digits from 0 - 9. By adding the eight numbers along the diagonal starting at the point defined by the starting digit of the known and satellite time sequence, one immediately gets the number of errors between the two sequences.

Table C-2 gives the results of doing this calculation on Table C-1.

Assuming the satellite message is error-free there will be no errors when the two sequences are the same; otherwise there are at least nine bit errors (by observing Table C-2).

The sequences are compared on the basis of less than 5-bit errors to handle the case when there are 4-bit errors in a sequence which would normally mismatch by 9 bits.

Table C-1

Number of Bit Errors between any Two
BCDX3 Digits

	0	1	2	3	4	5	6	7	8	9	0	1	2	3	4	0	1	2	3	4	5	6
0	0	3	2	2	1	3	2	2	1	4	0	3	2	2	1	0	3	2	2	1	3	2
1	3	0	1	1	2	2	3	3	4	1	3	0	1	1	2	3	0	1	1	2	2	3
2	2	1	0	2	1	3	2	4	3	2	2	1	0	2	1	2	1	0	2	1	3	2
3	2	1	2	0	1	3	4	2	3	2	2	1	2	0	1	2	1	2	0	1	3	4
4	1	2	1	1	0	4	3	3	2	3	1	2	1	1	0	1	2	1	1	0	4	3
5	3	2	3	3	4	0	1	1	2	1	3	2	3	3	4	3	2	3	3	4	0	1
6	2	3	2	4	3	1	0	2	1	2	2	3	2	4	3	2	3	2	4	3	1	0
7	2	3	4	2	3	1	2	0	1	2	2	3	4	2	3	2	3	4	2	3	1	2
8	1	4	3	3	2	2	1	1	0	3	1	4	3	3	2	1	4	3	3	2	2	1
9	4	1	2	2	3	1	2	2	3	0	4	1	2	2	3	4	1	2	2	3	1	2
0	0	3	2	2	1	3	2	2	1	4	0	3	2	2	1	0	3	2	2	1	3	2
1	3	0	1	1	2	2	3	3	4	1	3	0	1	1	2	3	0	1	1	2	2	3
2	2	1	0	2	1	3	2	4	3	2	2	1	0	2	1	2	1	0	2	1	3	2
3	2	1	2	0	1	3	4	2	3	2	2	1	2	0	1	2	1	2	0	1	3	4
4	1	2	1	1	0	4	3	3	2	3	1	2	1	1	0	1	2	1	1	0	4	3
0	0	3	2	2	1	3	2	2	1	4	0	3	2	2	1	0	3	2	2	1	3	2
1	3	0	1	1	2	2	3	3	4	1	3	0	1	1	2	3	0	1	1	2	2	3
2	2	1	0	2	1	3	2	4	3	2	2	1	0	2	1	2	1	0	2	1	3	2
3	2	1	2	0	1	3	4	2	3	2	2	1	2	0	1	2	1	2	0	1	3	4
4	1	2	1	1	0	4	3	3	2	3	1	2	1	1	0	1	2	1	1	0	4	3
5	3	2	3	3	4	0	1	1	2	1	3	2	3	3	4	3	2	3	3	4	0	1
6	2	3	2	4	3	1	0	2	1	2	2	3	2	4	3	2	3	2	4	3	1	0

Table C-2

Number of Errors when Comparing Two Eight-Digit Sequences Made up of the Least Significant Digits of the BCDX3 Modulo 15 Time Sequence

Beginning Digit of the Other Sequence	Beginning Digit of One Sequence: 0	1	2	3	4	5	6	7	8	9	0	1	2	3	4	Errors Min-Max
0	0	15	14	20	15	26	17	22	14	20	10	14	18	15	15	10 - 26
1	15	0	15	13	22	17	26	17	21	17	19	13	13	18	14	13 - 26
2	14	15	0	18	13	22	17	26	18	18	18	18	16	13	19	13 - 26
3	20	13	18	0	19	14	21	16	22	18	18	18	18	19	13	13 - 22
4	15	22	13	19	0	19	12	19	17	19	17	17	19	18	22	13 - 22
5	26	17	22	14	19	0	17	10	18	16	16	18	16	21	19	10 - 26
6	17	26	17	21	12	17	0	17	11	17	17	13	17	16	22	11 - 26
7	22	17	26	16	19	10	17	0	16	12	16	16	10	19	15	10 - 26
8	14	21	18	22	17	18	11	16	0	18	12	16	14	9	19	9 - 21
9	20	17	18	18	19	16	17	12	18	0	16	12	14	13	9	9 - 20
0	10	19	18	18	17	16	17	16	12	16	0	14	12	15	13	10 - 19
1	14	13	18	18	17	18	13	16	16	12	14	0	12	13	17	12 - 18
2	18	13	16	18	19	16	17	10	14	14	12	12	0	15	15	10 - 19
3	15	18	13	19	18	21	16	19	9	13	15	13	15	0	14	9 - 21
4	15	14	19	13	22	19	22	15	19	9	13	17	15	14	0	9 - 22

Example

Applying the above procedure to the data shown in Fig. 10 the following time sequences are obtained:

4 0 1 2 3 4 5 6 for the first message,

0 1 2 3 4 5 6 7 for the second message.

Now if a left end around shift is done to the following known sequence and the first eight digits are compared to the above sequences, it will be seen that 14 shifts are required for the first and 0 for the second.

$\boxed{0\ 1\ 2\ 3\ 4\ 5\ 6\ 7}\ 8\ 9\ 0\ 1\ 2\ 3\ 4$

If a match to less than 5-bit errors is not obtained in 14 shifts that message should not be used since it contains data that are too noisy.

Appendix D

TROPOSPHERIC REFRACTION CORRECTION

This Appendix presents the equations developed in Ref. 11 that are to be used if it is desired to correct the integrated doppler data obtained from the satellite for the effects of tropospheric refraction. The correction for tropospheric refraction $\Delta\rho_{tro}$ is to be subtracted from every slant range measurement. The expression for $\hat{S}_{ko}$, the measured slant range difference (Eq. (I.1) in Section 7), would thus be modified as follows:

$$\hat{S}_{ko_{corr}} = \hat{S}_{ko} - (\Delta\rho_{tro_{k+1}} - \Delta\rho_{tro_k}) \tag{D.1}$$

where k = 1, 2, 3, ---, KM .

The tropospheric refraction correction $\Delta\rho_{tro}$ is defined as follows:

$$\Delta\rho_{tro} = \sum_{i=1,2} \Delta\rho_i \tag{D.2}$$

where

$$\Delta\rho_i = 10^{-6} N_{T_i} \Bigg[-\ell_1 + \frac{4}{h_{tro_i}^4} \Bigg\{ \frac{1}{3} r_T^2 \ell_1^3 - \frac{2}{15} \ell_1^5 - \frac{3}{4} r_T r_{tro_i} \ell_1 (\ell_1^2 + \frac{1}{2} \ell_2^2)$$

$$+ r_{tro_i}^2 \ell_1^3 - \frac{1}{2} r_{tro_i}^3 r_T \ell_1 - \frac{1}{3} r_{tro_i}^2 \ell_{3_i}^3 + \frac{2}{15} \ell_{3_i}^5$$

$$+ \frac{3}{4} r_{tro_i}^2 (\ell_{3_i}^3 + \frac{1}{2} \ell_{3_i} \ell_2^2) - r_{tro_i}^2 \ell_{3_i} (\ell_{3_i}^2 - \frac{1}{2} r_{tro_i}^2)$$

$$+ \frac{1}{2} r_{tro_i} \ell_2^2 (\frac{3}{4} \ell_2^2 + r_{tro_i}^2) \ln \frac{r_T + \ell_1}{r_{tro_i} + \ell_{3_i}} \Bigg\} \Bigg]$$

and

i = subscript indicating dry (d) and wet (w) refractivity terms,

N_{T_i} = ith component of tropospheric refractivity evaluated at a location near the navigator's antenna,

ℓ_1 = $r_T \sin E$,

h_{tro_i} = $h_{o_i} - h_T$,

r_T = distance from center of earth to navigator's antenna (km),

r_{tro_i} = $r_T + h_{tro_i}$,

ℓ_2 = $r_T \cos E$,

ℓ_{3_i} = $(r^2_{tro_i} - \ell_2^2)^{1/2}$,

h_{o_i} = height of ith component of the troposphere above the geoid (km),

h_T = height of navigator's antenna above the geoid (km)

(on ships, negligible error is introduced by assuming $h_T = 0$), and

E = elevation angle of satellite at instant of slant range measurement (radians).

The dry and wet components of the tropospheric refractivity N_{T_i} are determined as follows:

$$N_{T_d} = \frac{77.6\, P}{T_K} \qquad \text{(D. 3)}$$

$$N_{T_w} = \frac{77.6\,(4810\, e)}{T_K^2} \qquad \text{(D. 4)}$$

where T_K = temperature (degrees Kelvin), P is total atmospheric pressure (millibars), and e is the partial pressure of water vapor (millibars) measured at the navigator's location. Alternatively, seasonal values for these parameters may be used as obtained from standard marine atlases (Refs. 12 and 13).

The determination of tropospheric height h_{o_i} is based on the assumption that the height of the wet component h_{o_w} is invariant with latitude, but that the height of the dry component h_{o_d} is a function of the navigator's latitude φ_T, as given in the following expression,

$$h_{o_d} = h_{o_{d(eq)}} + A_d \sin^2 \varphi_T , \tag{D.5}$$

where $h_{o_{d(eq)}}$ is the dry height at the equator and A_d is the amplitude of the variation of h_{o_d} with latitude. Values of these parameters for three values of h_{o_w} are given in Table D-1. A value of h_{o_w} = 12 km is generally satisfactory for use in all tropospheric refraction calculations.

Table D-1

Height Parameters for Two-Quartic N Profile (km)

h_{o_w}	$h_{o_{d(eq)}}$	A_d
10	43.858	-5.986
12	43.[illegible]30	-5.206
14	42.402	-4.426

ALTERNATIVE FORMS TO ELIMINATE ROUNDING ERRORS

At high satellite elevation angles, significant rounding errors occur in the computation of the expression

for $\Delta\rho_{tro}$ given in the preceding section, even in double precision. Alternative forms have been developed, therefore, to eliminate the rounding error problem and the need for double precision computation. These forms, which are presented in Ref. 14, are based upon the integral expression

$$\Delta\rho_{tro} = \frac{N_{T_i} \cdot 10^{-6}}{\left(h_{tro_i}\right)^4} \int_{-h_{tro_i}}^{0} \frac{\left(r_{tro_i} + x\right) x^4 \, dx}{\left[\left(r_{tro_i} + x\right)^2 - \ell_2^{\,2}\right]^{1/2}} . \quad (D.6)$$

Although this equation may be integrated in closed form, it results in inacceptable rounding errors, as stated above. An alternative form is obtained by expanding the integrand in series form and then performing the integration. This approach eliminates the problem of rounding errors. Two solutions are of interest: one for large values of E and one for small values. Their respective regions of rapid convergence sufficiently overlap so that the crossover value of E can be left to the discretion of the user. In addition to the two solutions presented below, a formula is given for estimating the error in truncating the series to a fixed number of terms. For convenience, the following parameters are defined:

$$W_1 = r_{tro_i} + \ell_2 ,$$

$$W_2 = r_{tro_i} - \ell_2 ,$$

$$W = W_1 W_2 .$$

Large Elevation Angles

$$\Delta\rho_{tro} = N_{T_i}\, 10^{-6}$$

$$\cdot \left\{ W^{1/2} - \ell_1 - \frac{0.8\, h_{tro_i}\, r_{tro_i}}{W^{1/2}} \right.$$

$$- W^{1/2} \sum_{p=0}^{\infty} \frac{1}{p+6} \left(\frac{h_{tro_i}}{W_2}\right)^{p+2} \tag{D. 7}$$

$$\cdot \left[2F\,(p+1) \left[1 + \left(\frac{W_2}{W_1}\right)^{p+2}\right] \right.$$

$$\left. \left. - \sum_{n=0}^{p} F(n)\, F(p-n) \left(\frac{W_2}{W_1}\right)^{n+1} \right] \right\}$$

where $F(k) = \binom{2k}{k} \dfrac{1}{(k+1)2^{2k}}$.

The recursive relationship

$$F(k) = 1/2 \quad \frac{(2k-1)}{k+1} \quad F(k-1) \tag{D. 8}$$

may be used to generate the F(k) for any desired range of values of k and eliminates having to compute factorials. The remainder in the expression for $\Delta\rho_{tro}$ after $p = 2^k - 2$ terms have been ısed may be estimated by

$$R_{\Delta\rho} < 4 \times 10^{-6}\, N_{T_i}\, W^{1/2}\, 2^{-3k/2} \left(\frac{h_{tro_i}}{W_2}\right)^{(2^k+1)} \quad . \tag{D. 9}$$

Small Elevation Angles

$$
\begin{aligned}
\Delta\rho = N_{T_i} \times 10^{-6}
& \cdot \left\{ -\ell_1 + 4 \frac{W_2^{\,5}}{h_{tro_i}^{\,4}} \left(\frac{W_1}{W_2} - 1 \right)^{1/2} \right. \\
& \cdot \sum_{n=0}^{3} (-1)^n \binom{3}{n} \\
& \cdot \left[\frac{2}{2n+3} \left[1 - \left(1 - \frac{h_{tro_i}}{W_2} \right)^{(2n+3)/2} \right] \right. \\
& + \sum_{p=0}^{\infty} (-1)^p \frac{F(p)}{(2p+2n+5)} \frac{1}{\left(\frac{W_1}{W_2} - 1 \right)^{p+3}} \\
& \left. \left. \cdot \left\{ 1 - \left(1 - \frac{h_{tro_i}}{W_2} \right)^{(2p+2n+5)/2} \right\} \right] \right\} .
\end{aligned}
\qquad \text{(D-10)}
$$

The remainder after $p = 2^k - 1$ terms is given by

$$
R_{\Delta\rho} < N_{T_i} \times 10^{-6} \left(\frac{W_2^{\,5}}{h_{tro_i}^{\,4}} \right) 2^{-3k/2} \left(\frac{W_2}{W_1 - W_2} \right)^{(2^k + 3/2)} \qquad \text{(D.11)}
$$

APPROXIMATION FOR SMALL COMPUTERS

The computations of the full expression for tropospheric range correction presented above require a fairly large computer. The following greatly simplified expressions have been developed for use where the computing facilities are limited.

The total range correction $\Delta\rho_{tro}$ at any elevation angle (i.e., any data point) is computed as the sum of the so-called "dry" and "wet" components, here subscripted d and w:

$$\Delta\rho_{tro} = (\Delta\rho_{tro})_d + (\Delta\rho_{tro})_w \,. \tag{D.12}$$

The simplest available approximations for the components are based on Ref. 15 and are as follows:

$$\left.\begin{aligned} (\Delta\rho_{tro})_d &= 2.31 \times 10^{-3} \csc\sqrt{E^2 + \theta_d^2}\ \text{km} \\ (\Delta\rho_{tro})_w &= 0.20 \times 10^{-3} \csc\sqrt{E^2 + \theta_w^2}\ \text{km} \end{aligned}\right\} \tag{D.13}$$

where E is the elevation angle of the satellite slant range vector and θ_d and θ_w are empirical parameters (angles); values will be given below. Equation (D.13) should be used only at sea level stations (ships or near-sea level land installations); the dry component of Eq. (D.13) is based on standard sea level pressure and the wet component on a marine rather than a continental climate.

For a little more accuracy, the following can be used instead of Eq. (D.13):

$$\left.\begin{aligned} (\Delta\rho_{tro})_d &= K_d\, P \csc\sqrt{E^2 + \theta_d^2} \\ (\Delta\rho_{tro})_w &= K_w \csc\sqrt{E^2 + \theta_w^2} \end{aligned}\right\} \,. \tag{D.14}$$

Here P is the observed local pressure (near antenna height). The parameter K_d is a constant and its value has been quite precisely determined from upper atmosphere data and theoretical considerations. Its current best value is $K_d = 2.278 \times 10^{-6}$ km/millibar. Using this value and the pressure P expressed in millibars, $(\Delta\rho_{tro})_d$ will be in kilometers.

The parameter K_w is not a constant but varies with latitude, season, and weather. An estimate may be made on the basis of qualitative observations and the observed average values presented in Table D-2.

Table D-2

Values of K_w for Selected Places and Times

K_w	Place, Time
0.28×10^{-3} km	Tropics or midlatitude summer
0.20×10^{-3} km	Midlatitude spring or fall
0.12×10^{-3} km	Midlatitude winter
0.05×10^{-3} km	Polar regions

The needed total range correction $\Delta\rho_{tro}$ for a single arriving ray is approximately 2.5 meters in the zenith direction and 90 meters at the horizon. The simplified expressions of Eqs. (D.13) and (D.14) are not very good at the horizon but are very good approximations at elevation angles higher than 5° and quite good as low as 2°, with the following parameter values:

$$\theta_d = 2.5°$$

$$\theta_w = 1.5° .$$

Uncorrected tropospheric errors do not affect navigation in the along-track direction unless there is a preponderance of data at one end of the pass. When symmetrical

amounts of data are present at both ends, the uncorrected troposphere affects only the apparent slant range (or coordinates dependent on it).

The average tropospheric effect, if uncorrected, pushes the navigator's position, obtained from a whole pass, approximately 20 meters toward the orbit in slant range for a high pass, and nearly 80 meters for a 15° pass (elevation 15° at closest approach). An error of 1% (10 millibars) in the pressure P used for the dry component in Eq. (D.14) affects the total range correction by not quite 1% (both the point-by-point correction and the effect on navigated range). An error of 0.1×10^{-3} in the magnitude of K_w (e.g., 0.20×10^{-3} instead of 0.10×10^{-3}) affects the total range correction by approximately 4% (both point-by-point and the effect on navigation).

The dry component generally contributes 90% or more of the total tropospheric correction at the higher angles (though the relative importance of the wet contribution increases at lower angles, especially below 5°). If local pressure is known to a millibar, the error in the dry component is negligible aside from the cosecant factor, and that error is small. Most of the uncertainty is due to the wet component, which (fortunately) is itself much the smaller component. The residual error in using Eq. (D.14) should be under 10% on the average.

Appendix E

COMPUTER PROGRAM FOR GEODETIC COORDINATE TRANSFORMATION

The following section is a paper which describes a technique for performing Geodetic Coordinate Transformations between ellipsoids. Although the procedure that has been developed employs approximations, it is felt that any inaccuracy introduced by these approximations is outweighed by the simplicity of the resulting equations.

The technique described has been programmed in Fortran for the 7094 computer, the Hewlett Packard 2115A computer, and also the Honeywell H-21 computer.

In order to improve the accuracy of the computation some minor modifications have been made to the equations. These modifications are described. A Fortran listing of the program and a sample printout generated by the program are also presented.

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NOTICES

The purpose of this paper is to disseminate results of technical research to activities engaged in geodesy and related subjects.

The opinions expressed in this report are those of the writer and should not be construed as necessarily coinciding with Air Force doctrine. The writer alone assumes the responsibility for the validity and accuracy of mathematical data contained herein.

LIST OF APPENDIXES

1. Purpose. The purpose of the tests was to determine the accuracy and the adaptability to electronic and machine computing of two formulas for transformation of geodetic data between reference ellipsoids. These formulas are designed for:

a. Transformation of latitude, longitude, and geodetic height (ref. [5] and App. B).

b. Computation of changes in geodetic distance and azimuths due to transformation of coordinates (ref. [6] and App. C).

2. Participating Organizations. The 1373rd Mapping and Charting Squadron (Data Control Division) provided position and inverse computations performed on E300AP II computer. The 1381st Geodetic Survey Squadron (Data Reduction Division) performed hand computations as well as electronic transformations of coordinates on RPC 4000 computer.

3. General Information.

a. The formulas of Appendixes B and C constitute a projective method of change of ellipsoid, as distinguished from development methods of earlier days. The characteristics of the two kinds of solution are summarized below.

b. Figure 1 shows points P and Q in space and a profile of a perpendicular section through these points. Curved lines represent ellipsoid and geoid surfaces and straight lines represent normals to ellipsoids, dashed lines referring to the old ellipsoid. The axes of the two ellipsoids are assumed to be mutually parallel. P_o and Q_o are the projections of P and Q upon the old ellipsoid and P_n and Q_n are their projections upon the new ellipsoid. The separation of ellipsoid

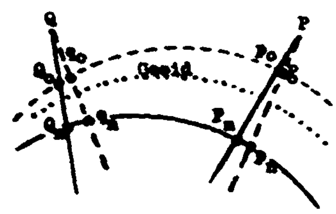

Figure 1.

surfaces at P is given by the distance $P_nP_o \doteq p_nP_o$, with a similar situation existing at Q. The geodetic distance on the old ellipsoid is the arc P_oQ_o and on the new ellipsoid it is P_nQ_n. The straight

line (spatial) distance PQ remains obviously the same before and after the transformation.

c. It is seen from Figure 1 that the effect of a projective method of transformation is to replace and reorient the reference ellipsoid, leaving all points in the same position in space as they were before the change took place. It follows that the angle between any two straight lines joining points in space must be the same before and after the transformation.

d. Thus the projective methods approach the problem in a truly rigorous way but they cannot remove the errors existing in the net due to errors of the survey, which includes errors caused by the reduction of distances to the geoid instead of the ellipsoid.*

e. Errors due to reduction of bases to the geoid instead of the ellipsoid are negligible in geodetic nets of limited extent if the ellipsoid fits the geoid reasonably well and if the two surfaces coincide at the origin. Herring, ref. [2], states that in the United States the geoid departs from the ellipsoid by only 1 meter at the distance of 30° from Meades Ranch. Taking 0.5 m as the average departure, we can calculate the error in geodetic distance due to this separation as less than 0.3 m at 3000 km, or 1 part in 10 million. This is much less than the expected error in measurement of a single line in Hiran trilateration and certainly much less than the error expected to accumulate through random errors of observation even in a most precise geodetic survey.

f. The development methods of transformation, such as are given in ref. [3] and [7], disregard the separation of geoid and ellipsoid surfaces and consider the distances and angles as the same on both ellipsoids. The effect of a development method is to recompute the net point by point on the new ellipsoid using old observational data. Any point taken at random cannot be transformed until the conversion

*The rise or fall of the geoid with respect to the ellipsoid may be obtained by astronomic or gravimetric surveys or by a combination of both methods. Astronomic determination of geoid heights requires observations for astronomic latitude and longitude at numerous stations.

has been extended to it from the origin. The new net will not match the old one, that is spatial distances and plane angles will be changed in transformation. The development method may be considered proper for local nets when the new ellipsoid is assumed to fit the geoid better than the old one but, when viewed as a transformation method, it is an approximation and an inconvenient one. It fails in transformations of global extent, in which case the departure of the geoid from an earth-centered ellipsoid of best fit may be quite large in any given area, such as 50 meters or more.

4. Testing Procedures.

a. Starting from stations 20, 50, and 80 in latitudes 20°, 50°, and 80°N respectively and in longitude 65°E, position computations were performed on Clarke 1866 Ellipsoid at distances 2000 km and in azimuths 90°, 135°, and 180° as shown in Figure 2.

b. In each group the ends of the lines were connected by inverse computations to form a quadrilateral with diagonals.

c. All stations were transformed to International Ellipsoid oriented with $\delta x = 90.904$ m, $\delta y = 108.335$ m, and $\delta z = 100.000$ m. This separation of ellipsoid centers was computed from arbitrary data at the origin chosen at $\phi = 40°N$, $\lambda = 5°E$. Geodetic heights at stations 22, 52, and 82 were assumed as 1000 m and at all other stations as zero. The transformation formula used was that of ref. [5] as shown in Appendix B. Results are shown in Appendix D.

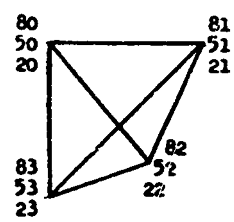

Figure 2.

d. Changes in distance and azimuth were computed over all lines, using the formula of reference [6] as shown in Appendix C. Then, using the International Ellipsoid values, rigorous inverse computations were performed over all lines. Results are shown in Appendix E.

e. The 1381st Geodetic Survey Squadron additionally tested the coordinate transformation formula against the Vening Meinesz formula by translating all stations from North American 1927 Datum to WGS 60, using both programs. The differences in results are shown in Appendix D.

5. Analysis of Results.

a. Ref. [2] analyses three projective methods of coordinate transformation: the space coordinate transformation formula, Baldini formula (ref. [1]), and Vening Meinesz formula (ref. [4]). One of the conclusions reached is that the Vening Meinesz formula is the least accurate of the three.

b. Ref. [5] compares a proposed formula with the Baldini and Vening Meinesz formulas and concludes that it is the simplest and the most accurate of the three. Its simplicity for both electronic and machine computing is due chiefly to the fact that it takes advantage of several constants which are precomputed once and for all for any particular change of ellipsoid. In addition, it permits accumulation of products without the necessity for recording intermediate results. Its accuracy in such cases as may occur in practice is shown to be of an order of 0.05 m at a distance halfway around the world from the origin (excluding areas in the immediate vicinity of the poles), with errors varying very slowly between distant points.

c. Appendix E shows the largest errors for a 2000-km line to be 0.010 m in distance and 0".0014 in azimuth, which represents proportional errors of 1:200 million and 1:140 million respectively. However, in rigorous computations the disagreement between forward and inverse computation results was found to be up to 0.005 m in distance and up to 0".0007 in azimuth, therefore the values in column (3) cannot all be correct to the last figure given. Consequently, actual errors should be smaller than those shown in column (5). Slightly larger errors are to be expected when the change of the ellipsoid is more violent than that shown in this example.

d. The coordinate transformation formula of Appendix B is very well suited for both electronic and machine computing. It was programmed for the RPC 4000 computer by the 1381st Geodetic Survey Squadron quickly and without difficulty. That squadron rated hand computations involving this formula on a scale of increasing difficulty from 1 (represented by Hiran minimum sum computation) to 10 (represented by Hiran ΔH and ΔN computation) and gave it a rating of 3. The average time for completing the computation form was determined as about 25 minutes.

e. The formula of Appendix C is easy for use with a calculator because of few significant figures and no interpolation required. The 1381st Squadron gave it a rating of 5 on the same scale of difficulty as in paragraph 5d after determining that the average time necessary to complete the form was about 40 minutes. It is believed that this rating is a little too pessimistic and that computations should be completed within 30 minutes, particularly for short lines or when lesser accuracy is acceptable, as in Hiran trilateration.

f. No programming of the formula of Appendix C was undertaken, but it is believed that this should present no difficulties. The computer time should be a fraction of the time required to run an inverse computation. If this formula were to be programmed separately in the form as given here, it would require an input of several quantities (old positions and elevations, changes in ϕ, λ, and H, old distance, and old azimuths). However, it could be programmed in one package together with the coordinate transformation formula, in which case the only additional input data would be old distance and old azimuths.

6. Conclusions.

a. The formulas of Appendixes B and C can be advantageously adopted for hand computing when the electronic computer is inoperative or in use for higher priority projects. In this case all constants should be precomputed and printed on the computation form.

Alternatively, if the activity concerned has contact with several ellipsoids, the several sets of constants can be shown on a separate sheet.

b. The formula of Appendix B can be programmed for an electronic computer in a few hours, or in much less time than it took to type this report. From the accuracy point of view the Vening Meinesz formula which many activities now use is satisfactory. However, after a new world geodetic system is prescribed, as will certainly happen in the future, there will be no reason for using the Vening Meinesz formula, since easier and more accurate methods are now available.

c. The formula of Appendix C can be evaluated by each activity concerned to determine whether it would be more profitable to program it or to continue to use inverse computations, depending on operational requirements.

APPENDIX A

NOTATION

ϕ, λ = geodetic latitude and longitude. λ positive east.

H = height of point above ellipsoid (geodetic height).

α = azimuth of the geodesic, clockwise from north.

S = geodetic distance.

a, b = major and minor semiaxes of the ellipsoid.

e = $(a^2 - b^2)^{\frac{1}{2}}/a$ = first eccentricity.

ϵ = $e^2/(1 - e^2)$ = the square of second eccentricity.

N = radius of curvature in the prime vertical = $a(1-e^2\sin^2\phi)^{-\frac{1}{2}}$.

R = approximate radius of the Earth.

$\bar{a}$ = $\frac{1}{2}(a_o + a_n)$.

$\bar{\epsilon}$ = $\frac{1}{2}(\epsilon_o + \epsilon_n)$.

x, y, z = rectangular space coordinates, i.e.

$x = (N + H)\cos\phi \cos\lambda$

$y = (N + H)\cos\phi \sin\lambda$

$z = [N(1 - e^2) + H]\sin\phi$.

$\delta\phi$, $\delta\lambda$, δH = $\phi_n - \phi_o$ etc. = shifts in latitude, longitude and geodetic height. δH is the height of the old ellipsoid above the new one.

δx, δy, δz = rectangular components of separation of ellipsoid centers.

δa, δe^2 = $a_n - a_o$ and $e_n^2 - e_o^2$.

$\delta\alpha$, δS = $\alpha_n - \alpha_o$ and $S_n - S_o$.

Subscripts o and n refer to the old and the new ellipsoid respectively. Subscripts 1 and 2 refer to the ends of a geodetic line. α_1 is the forward azimuth and α_2 is the back azimuth.

APPENDIX B

FORMULA FOR TRANSFORMATION OF COORDINATES

To compute changes in latitude, longitude, and geodetic height:

$$\delta\phi'' = [(A_1\cos\lambda + A_2\sin\lambda)\sin\phi + A_3\cos\phi]V + (A_4\sin^2\phi + A_5)\sin\phi\cos\phi \qquad (1a)$$

$$\delta\lambda'' = (A_1\sin\lambda - A_2\cos\lambda)W\sec\phi \qquad (1b)$$

$$\delta H = (B_1\cos\lambda + B_2\sin\lambda)\cos\phi + B_3\sin\phi + B_4\sin^2\phi + B_5\sin^4\phi + B_6 \qquad (1c)$$

To compute the separation of ellipsoid centers if changes in latitude, longitude, and geodetic height are known at any point:

$$\delta x = \frac{1}{V}(C_1\sin\phi\cos\phi + C_2\delta\phi'')\sin\phi\cos\lambda + \left[\frac{1}{W}C_2\delta\lambda''\sin\lambda + (\delta H + C_3)\cos\lambda\right]\cos\phi \qquad (2a)$$

$$\delta y = \frac{1}{V}(C_1\sin\phi\cos\phi + C_2\delta\phi'')\sin\phi\sin\lambda + \left[-\frac{1}{W}C_2\delta\lambda''\cos\lambda + (\delta H + C_3)\sin\lambda\right]\cos\phi \qquad (2b)$$

$$\delta z = -\frac{1}{V}(C_1\sin\phi\cos\phi + C_2\delta\phi'')\cos\phi + (\delta H + D_1 + D_2\sin^2\phi + D_3\sin^4\phi)\sin\phi \qquad (2c)$$

The following are constants which may be precomputed:

$A_1 = -(\csc 1''/a)\,\delta x$	$C_1 = \frac{1}{2} f\,\delta a + \frac{1}{2}(1+f)a\,\delta e^2$
$A_2 = -(\csc 1''/a)\,\delta y$	$C_2 = -a\sin 1''$
$A_3 = (\csc 1''/a)\,\delta z$	$C_3 = \delta a$
$A_4 = -\frac{1}{2} f \csc 1''\,\delta e^2$	$D_1 = [1 - \frac{1}{2}f(1-f)]\delta a - \frac{1}{2}a\,\delta e^2$
$A_5 = [(f/a)\delta a + (1+f)\delta e^2]\csc 1''$	$D_2 = -B_5$
$B_1 = \delta x$	$D_3 = -\frac{1}{2}f^2\delta a$
$B_2 = \delta y$	
$B_3 = \delta z$	
$B_4 = \frac{1}{2} f\,\delta a + \frac{1}{2} a\,\delta e^2$	
$B_5 = \frac{1}{2} f^2\delta a + \frac{1}{4} a f\,\delta e^2$	
$B_6 = -\delta a$	

Additionally, $V = 1 + f(1 - \frac{3}{2}\sin^2\phi)$ and $W = 1 - \frac{1}{2} f \sin^2\phi$.

Above equations are applicable to a point on the surface of the ellipsoid. In a general case of a point at height H, multiply each term in $\delta\phi$ and $\delta\lambda$ in eq. (2) by $(1+H/R)$ and the results of eq. (1a) and (1b) by $(1-H/R)$, where $1/R \doteq 0.157 \times 10^{-6}$ meters. Elevation above geoid may be substituted for H without introducing an appreciable error. Five-figure computations are sufficient.

APPENDIX C

FORMULA FOR CHANGES IN DISTANCE AND AZIMUTHS

$$\alpha_m = \alpha_1 + \alpha_2 \qquad (3)$$

$$r = a\left(1 - \tfrac{1}{2}e[(2 - \cos\alpha_m)\cos^2\tfrac{1}{2}(\phi_1+\phi_2) - 1]\right) \qquad (4)$$

$$\theta = S/r \qquad (5)$$

$$\sin\phi_m = \sin\phi_1\cos\tfrac{1}{2}\theta + \cos\phi_1\sin\tfrac{1}{2}\theta\,\cos\alpha_1 \qquad (6)$$

$$\sin\Delta\lambda = \sin\tfrac{1}{2}\theta\,\sin\alpha_1\sec\phi_m \qquad (7)$$

$$\lambda_m = \lambda_1 + \Delta\lambda \qquad (8)$$

Now compute δH_m for (ϕ_m, λ_m) by eq. (10). Then

$$\delta\bar{H} = (\delta H_1 + 4\delta H_m + \delta H_2)/6 \qquad (9)$$

$$\delta S = -\theta\,\delta\bar{H} + H_1\cos\alpha_1\delta\phi_1 + H_2\cos\alpha_2\delta\phi_2 + (H_1\delta\lambda_1 - H_2\delta\lambda_2)\cos\phi_1\sin\alpha_1 \qquad (10)$$

$$T = (H_2 - H_1)/S - \tfrac{1}{2}\theta\left(1 + \tfrac{1}{12}\theta^2\right) \qquad (11)$$

$$U = \sin\alpha_1\delta\phi_1 - \cos\phi_1\cos\alpha_1\delta\lambda_1 \qquad (12)$$

$$\delta\alpha_1 = \sin\phi_1\delta\lambda_1 + TU - \tfrac{1}{6}\theta^2\cos\phi_1\sin\alpha_1(\cos\phi_1\cos\alpha_1 - \tfrac{1}{4}\theta\sin\phi_1)\delta e^2$$
$$- \tfrac{1}{2}e\cos^2\tfrac{1}{2}(\phi_1+\phi_2)\sin\alpha_m\delta H_2/R \qquad (13)$$

To compute $\delta\alpha_2$, use (11), (12), and (13) with subscripts 1 and 2 reversed.

$\delta\phi$ and $\delta\lambda$ are in radians.

For lines up to 250 km omit the θ^3 term in eq. (11) and use

$$\delta\alpha_1 = \sin\phi_1\delta\lambda_1 + TU + \tfrac{1}{12}\theta^2\cos^2\tfrac{1}{2}(\phi_1+\phi_2)\sin\alpha_m\delta e^2$$
$$- \tfrac{1}{2}e\cos^2\tfrac{1}{2}(\phi_1+\phi_2)\sin\alpha_m d\bar{H}/R \qquad (13')$$

For ground triangulation lines omit (6), (7), and (8) and use

$$\delta\bar{H} = \tfrac{1}{2}(\delta H_1 + \delta H_2) \qquad (9')$$

For lesser accuracy, as in aerial electronic trilateration, use only the first term of eq. (10), omit the term in θ^3 in eq. (11), and omit the last term of eq. (13).

Five-figure computations are sufficient.

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A more convenient form of equation (6), not used in test computations, is

$$\sin\phi_m = \tfrac{1}{2}(\sin\phi_1 + \sin\phi_2)\sec\tfrac{1}{2}\theta \qquad (6_1)$$

Further simplifications of equations (6) and (7) are achieved by using for lines of intermediate length

$$\sin\phi_m = \tfrac{1}{2}(\sin\phi_1 + \sin\phi_2)(1 + \tfrac{1}{8}\theta^2) \qquad (6')$$

$$\sin\Delta\lambda = \tfrac{1}{2}\,\theta\,\sin\alpha_1\sec\phi_m(1 - \tfrac{1}{24}\theta^2) \qquad (7')$$

Equations (6') and (7') were not tested extensively but it is believed that the errors in δR_m due to their approximations will not change the final result by more than 0.005 m at 1000 km.

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APPENDIX D

RESULTS OF TRANSFORMATION OF COORDINATES

I. From Clarke 1866 to International Ellipsoid by Vincenty method.
δx = 90.904 m, δy = 108.335 m, δz = 100.000 m.

STA	ø	λ	H	δø	δλ	δH
20	20°00'00".0000N	65°00'00".0000E	0 m	-1".5188	-1".2591	-36.124 m
21	18 58 51.7574	84 01 51.1926	0	-1.0883	-2.7056	-53.702
22	6 50 01.2011	77 41 18.3625	1000	+1.6234	-2.1398	-47.432
23	1 55 10.2032	65 00 00.0000	0	+2.7863	-1.1843	-41.888
50	50 00 00.0000	65 00 00.0000	0	5.9800	-1.8378	-103.062
51	46 46 45.2454	91 43 14.1278	0	-5.0107	-4.4364	-114.136
52	36 01 24.5469	80 37 35.9501	1000	-4.2157	-2.8769	-74.939
53	31 59 26.3418	65 00 00.0000	0	-3.8651	-1.3943	-53.794
80	80 00 00.0000	65 00 00.0000	0	-5.3982	-6.7941	-201.505
81	69 33 49.1212	126 44 47.5999	0	-2.9561	-12.7110	-205.195
82	64 03 27.2886	94 49 06.5703	1000	-5.2304	-7.3474	-166.210
83	52 04 27.4728	65 00 00.0000	0	-6.3107	-2.5208	-143.585

II. From Clarke 1866 to International Ellipsoid by Vincenty and exact space coordinate methods. δx, δy, and δz as above. ø = 40°00'00".0000S, λ = 95°00'00".0000E, H = 0.000 m. (The exact method uses equations for x, y, and z as shown in Appendix A and their inverse forms, e. g. [5]).

		δø	δλ	δH
(1)	Vincenty	+9".2440	-4".2156	-229.701 m
(2)	Exact	+9.2442	-4.2156	-229.696
	Error	0.0002	0.0000	0.005 (Total error = 0.007 m)

III. From North American 1927 Datum to WGS 60 by Vincenty and Vening Meinesz methods. Only the differences in results (Vincenty minus Vening Meinesz) are given.

STA	Δδø	Δδλ	STA	Δδø	Δδλ
20	+0".0029	+0".0006	52	-0".0039	+0".0011
21	+0.0028	+0.0010	53	-0.0038	+0.0006
22	+0.0016	+0.0008	80	-0.0023	+0.0031
23	+0.0009	+0.0005	81	-0.0022	+0.0040
50	-0.0042	+0.0008	82	-0.0032	+0.0026
51	-0.0039	+0.0016	83	-0.0037	+0.0012

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APPENDIX E

RESULTS OF TRANSFORMATION OF AZIMUTHS AND DISTANCES

Line	Clarke 1866 Fwd. Az. Back Az. Geod. Distance	Intern. Fwd. Az. Back Az. Geod. Dist.	Change (2)-(1)	Vincenty Formula	Error (4)-(3)
	(1)	(2)	(3)	(4)	(5)
20-21	90°00'00"0000	59"8060	-0"1940	-0"1940	0"0000
	276 [illegible] 09.3789	08.2714	-1.1075	-1.1073	0.0002
	2 000 000.000 m	13.762 m	13.762 m	13.765 m	0.002 m
20-22	135 00 00.0000	59.8040	-0.1960	-0.1955	0.0005
	317 58 31.2446	30.8384	-0.4062	-0.4048	0.0014
	2 000 000.000	12.417	12.417	12.427	0.010
20-23	180 00 00.0000	59.7576	-0.2424	-0.2424	0.0000
	0 00 00.0000	59.7720	-0.2280	-0.2280	0.0000
	2 000 000.000	11.213	11.213	11.205	0.008
21-22	207 54 07.8411	07.1994	-0.6417	-0.6421	0.0005
	26 28 33.6267	33.0881	-0.5386	-0.5396	0.0010
	1 509 168.813	80.450	11.637	11.636	0.001
21-23	229 57 45.3834	44.8287	-0.5547	-0.5590	0.0043
	46 26 25.4873	24.9637	-0.5236	-0.5280	0.0044
	2 804 710.238	29.445	19.207	19.187	0.020
22-23	249 28 27.3893	27.4314	+0.0421	+0.0426	0.0005
	68 30 04.0390	03.6669	-0.3721	-0.3711	0.0010
	1 509 158.629	69.019	10.390	10.385	0.005
50-51	90 00 00.0000	50.5315	-0.4685	-0.4684	0.0001
	290 08 48.8458	44.6888	-4.1570	-4.1563	0.0007
	2 000 000.000	34.001	34.001	34.009	0.008
50-52	135 00 00.0000	59.3588	-0.6412	-0.6415	0.0003
	325 46 29.9818	27.5698	-2.4120	-2.4115	0.0005
	2 000 000.000	27.606	27.606	27.610	0.004
50-5	180 00 00.0000	58.7793	-1.2207	-1.2206	0.0001
	0 00 00.0000	59.0739	-0.9260	-0.9260	0.0000
	2 000 000.000	24.108	24.108	24.108	0.000
51-52	221 39 08.1528	04.8215	-3.3413	-3.3404	0.0009
	34 16 12.2452	10.6256	-1.6196	-1.6193	0.0003
	1 509 296.352	18.582	22.230	22.227	0.003
51-53	243 42 55.0029	51.1367	-3.8662	-3.8674	0.0012
	46 25 56.9819	56.7810	-0.2009	-0.2032	0.0023
	2 804 850.319	86.531	36.212	36.222	0.010
52-53	257 16 44.4955	42.3868	-2.1087	-2.1094	0.0007
	68 29 46.0656	45.7173	-0.3483	-0.3489	0.0006
	1 509 276.249	91.386	15.137	15.140	0.003

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	(1)	(2)	(3)	(4)	(5)
80–81	90 00 00.0000	54.1592	-5.8408	-5.8410	0.0002
	330 10 00.3747	47.6204	-12.7542	-12.7542	0.0001
	2 000 000.000 m	63.966 m	63.966 m	63.965 m	0.001 m
80–82	135 00 00.0000	54.0378	-5.9622	-5.9622	0.0000
	243 41 24.3278	16.9954	-7.3324	-7.3320	0.0004
	2 000 000.000	57.779	57.779	57.773	0.006
80–83	180 00 00.0000	53.4949	-6.5051	-6.5048	0.0003
	0 00 00.0000	57.5863	-2.4137	-2.4134	0.0003
	2 000 000.000	54.216	54.216	54.211	0.005
81–82	261 40 39.0634	26.8843	-12.1791	-12.1789	0.0002
	152 10 46.2197	39.8743	-6.3454	-6.3454	0.0000
	1 509 414.654	58.589	43.935	43.934	0.001
81–83	283 44 36.1541	23.3688	-12.7853	-12.7849	0.0004
	46 25 25.4062	24.0379	-1.3682	-1.3686	0.0004
	2 804 987.582	64.874	77.292	77.297	0.005
82–83	275 12 01.2084	53.9452	-7.2632	-7.2631	0.0001
	168 29 23.3547	21.7720	-1.5827	-1.5826	0.0001
	1 509 407.176	43.844	36.668	36.672	0.004

APPENDIX F

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FORMULA FOR TRANSFORMATION OF GEODETIC COORDINATES

There are seven parameters used in this computation which specify the datums involved in the transformation. They are:

1. $A\varphi$ – The semimajor axis of the reference ellipsoid in the original datum.
2. $F\varphi$ – The reciprocal flattening of the reference ellipsoid of the original datum.
3. AN – The semimajor axis of the reference ellipsoid in the new datum.
4. FN – The reciprocal flattening of the reference ellipsoid of the new datum.
5. DX – The x-axis origin offset between the two geodetic systems.
6. DY – The y-axis origin offset between the two geodetic systems.
7. DZ – The z-axis origin offset between the two geodetic systems.

The equations which have been implemented in the program, GEOCN (Geodetic Coordinate Conversion Program) are:

$$\delta\varphi'' = \Big[\left[(A_1 \cos\lambda + A_2 \sin\lambda) \sin\varphi + A_3 \cos\varphi\right] V + (A_4 \sin^2\varphi + A_5) \sin\varphi \cos\varphi\Big] \left[1 - \frac{H}{A\varphi}\right]$$

$$\delta\lambda'' = \left[(A_1 \sin\lambda - A_2 \cos\lambda) \frac{w}{\cos(\varphi)}\right] \left[1 - \frac{H}{A\varphi}\right]$$

$$\delta H = (DX \cos\lambda + DY \sin\lambda) \cos\varphi + DZ \sin\varphi + B_4 \sin^2\varphi + B_5 \sin^4\varphi + B$$

where

$A_1 \quad = -\frac{\csc(1'')}{\mathring{a}} DX$

$A_2 \quad = -\frac{\csc(1'')}{\mathring{a}} DY$

$A_3 \quad = \frac{\csc(1'')}{\mathring{a}} DZ$

$A_4 \quad = -0.5\ (\dot{\epsilon}\ \csc(1'')\ de^2)$

$A_5 \quad = \left[\left(\frac{\dot{\epsilon}}{\mathring{a}}\right) da + (1 + \dot{\epsilon})\ de^2\right]\ \csc(1'')$

$B_4 \quad = 0.5\ (\mathring{a}\ de^2 - \dot{\epsilon}\ da)$

$B_5 \quad = B_4 \cdot \mathring{d}e^2 - (0\ 25)\ (\mathring{a} \cdot \dot{\epsilon} \cdot de^2)$

$B_6 \quad = A\varphi - AN$

$V \quad = 1 + \dot{\epsilon}\ (1 - 1.5\ \sin^2(\varphi))$

$W \quad = 1 - 0.5\ \ \dot{\epsilon}\ \sin^2(\varphi)$

φ = Latitude of reference position in original datum.

λ = Longitude of reference position in original datum.

H = Height of reference position above reference ellipsoid in original datum.

From the preceding paper:

$\mathring{a} \quad = 0.5\ (A\varphi + AN)$

$e \quad = \frac{(a^2 - b^2)^{1/2}}{a}$

$\epsilon \quad = \frac{e^2}{(1 - e^2)}$

$\dot{\epsilon}$ $\quad$ $- \frac{1}{2}(\epsilon_{\varphi} + \epsilon_n)$

$da = a_n - a_{\varphi}$

$de^2 = e_n^2 - e_o^2$

But for an ellipse:

$b = a\left(1 - \frac{1}{f}\right)$

a = Semimajor axis

b = Semiminor axis

f = Reciprocal flattening.

Then:

$$b = a\left(\frac{f-1}{f}\right)$$

$$\frac{b}{a} = \frac{f-1}{f}$$

and

$$\frac{a}{b} = \frac{f}{f-1}$$

$$e^2 = \frac{a^2-b^2}{a^2} = 1 - \frac{b^2}{a^2} = 1 - \left(\frac{f-1}{f}\right)^2$$

$$\epsilon = \frac{e^2}{1-e^2} = \frac{1 - \left(\frac{f-1}{f}\right)^2}{1 - 1 \div \left(\frac{f-1}{f}\right)^2}$$

$$\epsilon = \frac{1 - \left(\frac{f-1}{f}\right)^2}{{\frac{f-1}{f}}^2} = \left(\frac{f}{f-1}\right)^2 - 1$$

$$\dot{\epsilon} = \frac{1}{2}\left[\left(\frac{F\varphi}{F\varphi-1}\right)^2 + \left(\frac{FN}{FN-1}\right)^2\right] - 1$$

$$de^2 = \left[\frac{F\varphi-1}{F\varphi}\right]^2 - \left[\frac{FN-1}{FN}\right]^2$$

FORTRAN LISTING


```
C
C     --- 1/3/69 VERSION ---
C
    1 FORMAT (5X,F9.3,6X,F10.4)
    2 FORMAT (9X,F9.6,1X,F9.6,1X,F9.6)
    3 FORMAT (I3,3X,F5.0,1X,F7.4,1X,F7.4,2X,
     1        F5.0,1X,F7.4,1X,F7.4,4X,F8.1)
    4 FORMAT (2/)
    5 FORMAT ( 5X,23HINPUT STATION POSITION ,///,
     1         29HSTA   LATITUDE                 ,
     2         36HLONGITUDE                  ANT. HEIGHT ,/,
     3         29HNNN   SDDD. MM.MMMM SS.SSSS    ,
     4         36HSDDD. MM.MMMM SS.SSSS    SMMMMM.M      )
    6 FORMAT ( 5X,34HGEODETIC COORDINATE TRANSFORMATION,
     1         5/)
    7 FORMAT ( 5X,24HORIGINAL     DATUM - A = ,F8.3,
     1         12H KM    F = 1/,F7.3,3/)
    8 FORMAT ( 5X,24HTRANSFORMED DATUM - A = ,F8.3,
     1         12H KM    F = 1/,F7.3,3/)
    9 FORMAT ( 5X,5HDX = ,F7.5,4H  KM,5X,5HDY = ,
     1         F7.5,4H  KM,5X,5HDZ = ,F7.5,4H  KM,3/)
   10 FORMAT ( 5X,22HREFERENCE POSITION IN ,
     1         16HORIGINAL DATUM -,//)
   11 FORMAT ( 5X,12HLATITUDE  - ,F5.0,5H DEG ,F7.4,
     1         5H MIN ,F7.4,5H SEC ,/)
   12 FORMAT ( 5X,12HLONGITUDE - ,F5.0,5H DEG ,F7.4,
     1         5H MIN ,F7.4,5H SEC ,/)
   13 FORMAT ( 5X,22HREFERENCE POSITION IN ,
     1         19HTRANSFORMED DATUM -,//)
   14 FORMAT ( 5X,7HDLAT = ,F8.4,4H SEC,5X,7HDLON = ,
     1         F8.4,4H SEC,5X,5HDH = ,F7.1,7H METERS,/)
   15 FORMAT ( 5X,7HDLAT = ,F8.4,4H MIN,5X,7HDLON = ,
     1         F8.4,4H MIN,/)
   16 FORMAT ( 5X,7HDLAT = ,F8.4,4H NM ,5X,7HDLON = ,
     1         F8.4,4H NM ,/)
   17 FORMAT ( 5X,5HA1 = ,E15.8,/, 5X,5HA2 = ,E15.8,/,
     1          5X,5HA3 = ,E15.8,/, 5X,5HA4 = ,E15.8,/,
     2          5X,5HA5 = ,E15.8,//)
   18 FORMAT ( 5X,18HGEOIDAL HEIGHT -  ,F8.1,7H METERS,4/)
   19 FORMAT ( 5X,7HEDOT = ,E15.8,5X,6HDE2 = ,E15.8,8/)
   20 FORMAT ( 5X,10HSTATION    ,I3,//)
   21 FORMAT ( 5X,27HINPUT ELLIPSOID PARAMETERS   ,/,
     1          5X,27HSEMI AXIS      REC. FLAT.    ,/,
     2          5X,27HKKKK.KKKK      FFF.FFFFF      )
   22 FORMAT ( 5X,27HINPUT ORIGIN OFFSETS          ,/,
     1          9X,29HDX - KM   DY - KM   DZ - KM  ,/,
     2          9X,30HSX.XXXXXX SX.XXXXXX SX.XXXXXX  )
      KI=1
      KO=2
      CON=4.848136811E-6
   92 WRITE(KO,21)
      READ(KI,1) AO,FO
      READ(KI,1) AN,FN
      WRITE(KO,22)
      READ(KI,2) DX,DY,DZ
  100 WRITE(KO,5)
      READ(KI,3) KSTA,RLATD,RLATM,RLATS,RLOND,RLONM,
     1           RLONS,GHO
      PAUSE
      IF(KSTA) 99,101,101
  101 TEMP= ABS(RLATD)
      FLATS=SIGN((TEMP*60.+RLATM)*60.+RLATS,RLATD)
```

```
      [illegible]
      CLATR=CLATS*CON
      CLONR=CLONS*CON
      ADOT= (AO+AN)/2.
      DFO= ((FO-1.)/FO)
      DFN= ((FN-1.)/FN)
      DFO2= DFO*DFO
      DFN2= DFN*DFN
      EDOT= ((1./DFO2)+(1./DFN2))/2.-1.
      DE2= DFO2-DFN2
      CONA= CON*ADOT
      CONE2= DE2/CON
      GHCON= (1.-(GHO*1.E-3)/AO)
      A1= -DX/CONA
      A2= -DY/CONA
      A3=  DZ/CONA
      A4= -0.5*EDOT*CONE2
      A5= (EDOT/CONA)*(AN-AO)+(1.+EDOT)*CONE2
      CLAT= COS(CLATR)
      SLAT= SIN(CLATR)
      CLON= COS(CLONR)
      SLON= SIN(CLONR)
      S2LAT= SLAT*SLAT
      V= 1.+EDOT*(1.-1.5*S2LAT)
      W= 1.-0.5*EDOT*S2LAT
      DLAT= ((A1*CLON+A2*SLON)*SLAT+A3*CLAT)*V
     1      +(A4*S2LAT+A5)*SLAT*CLAT
      DLAT= DLAT*GHCON
      DLON= (A1*SLON-A2*CLON)*W/CLAT
      DLON= DLON*GHCON
      B6= (AO-AN)
      B4= (ADOT*DE2-EDOT*B6)*0.5
      B5= B4*EDOT-0.25*ADOT*EDOT*DE2
      DHKM= (DX*CLON+DY*SLON)*CLAT+DZ*SLAT
     1      +B4*S2LAT+B5*(S2LAT*S2LAT)+B6
      DHM= DHKM*1.E+3
      GHN= GHO+DHM
      DLATM= DLAT/60.
      DLATN= DLATM
      DLONM= DLON/60.
      DLONN= DLONM*CLAT
      ELATS=CLATS+DLAT
      ELONS=CLONS+DLON
      TEMP=ELATS/3600.
      FLATD=IFIX(TEMP)
      TEMP1=ABS(ELATS-FLATD*3600.)/60.
      FLATM=IFIX(TEMP1)
      FLATS=(TEMP1-FLATM)*60.
      TEMP2=ELONS/3600.
      FLOND=IFIX(TEMP2)
      TEMP3=ABS(ELONS-FLOND*3600.)/60.
      FLONM=IFIX(TEMP3)
      FLONS=(TEMP3-FLONM)*60.
  122 CONTINUE
      WRITE(KO,4)
      WRITE(KO,6)
      WRITE(KO,7) AO,FO
      WRITE(KO,8) AN,FN
      WRITE(KO,9) DX,DY,DZ
  123 WRITE(KO,20) KSTA
  124 WRITE(KO,10)
      WRITE(KO,11) RLATD,RLATM,RLATS
      WRITE(KO,12) RLOND,RLONM,RLONS
      WRITE(KO,18) GHO
```

```
      WRITE(KO,12) FLOND,FLONM,FLONS
      WRITE(KO,18) GHN
      WRITE(KO,14) DLAT,DLON,DHM
      WRITE(KO,15) DLATM,DLONM
      WRITE(KO,16) DLATN,DLONN
      WRITE(KO,17) A1,A2,A3,A4,A5
      WRITE(KO,19) EDOT,DE2
      GO TO 100
      END
END OF TAPE
```

E.4 SAMPLE PRINTOUT


```
INPUT ELLIPSOID PARAMETERS
SEMI AXIS        REC. FLAT.
KKKK.KKKK        FFF.FFFFF
6378.206         294.978
6378.144         298.230
INPUT ORIGIN OFFSETS
    DX - KM    DY - KM    DZ - KM
    SX.XXXXXX SX.XXXXXX SX.XXXXXX
    -0.025      .173        .183
INPUT STATION POSITION

STA  LATITUDE                  LONGITUDE                 ANT. HEIGHT
NNN  SDDD. MM.MMMM SS.SSSS     SDDD. MM.MMMM SS.SSSS     SMMMMM.M
1    +039.  9.8165             -076. 53.8643             +  145.
PAUSE
```

GEODETIC COORDINATE TRANSFORMATION

ORIGINAL DATUM - A = 6378.206 KM F = 1/294.978

TRANSFORMED DATUM - A = 6378.144 KM F = 1/298.239

DX = -.02500 KM DY = -.17300 KM DZ = .18300 KM

STATION 1

REFERENCE POSITION IN ORIGINAL DATUM -

LATITUDE - 39. DEG 9.8165 MIN .0000 SEC

LONGITUDE - -76. DEG 53.8643 MIN .0000 SEC

GEOIDAL HEIGHT - 145.0 METERS

REFERENCE POSITION IN TRANSFORMED DATUM -

LATITUDE - 39. DEG 9.0000 MIN 49.6875 SEC

LONGITUDE - -76. DEG 53.0000 MIN 51.2498 SEC

GEOIDAL HEIGHT - 94.1 METERS

DLAT = .6799 SEC DLON = .6193 SEC DH = -50.9 METERS

DLAT = .0113 MIN DLON = .0103 MIN

DLAT = .0113 NM DLON = .0080 NM

A1 = .80847895E+00
A2 = -.55946750E+01
A3 = .59169660E+01
A4 = .51494971E-01
A5 = -.15312498E+02

EDOT = .67775249E-02 DE2 = -.73671341E-04

Appendix F

GLOSSARY OF TERMS FOR NAVIGATION SOLUTION COMPUTATION

Term or Symbol	Fortran Name	Meaning
A_o	AO	Semimajor axis of orbit ellipse.
ΔA_k	DA(K)	Incremental length of semimajor axis of orbit ellipse.
a_{nj}		Coefficients in the navigation equation, constant for any interval for which a doppler count is obtained.
c		Speed of light in a vacuum.
$C_{ko}(f, \varphi, \lambda)$		Difference between measured slant range difference and theoretical slant range difference.
d	HEAD	Navigator's heading at estimated first fiducial time.
ΔE_k	DE(K)	Incremental eccentric anomaly.
ϵ	E	Eccentricity of satellite orbit.
$\bar{f}_o$	EFRQ	Initial value of offset frequency.
$\bar{f}$	EFRQ	Improved estimate of offset frequency resulting from navigation operations.
GMT		Greenwich Mean Time.
h		Station's antenna height above mean sea level.
H		Height of sea level above reference geoid at station's position.
h'	GEOH	Station's antenna height above geoid (= h + H).

Term or Symbol	Fortran Name	Meaning
KM-1	KM-1	Total number of intervals for which doppler counts have been obtained during a given satellite pass.
k	K	Index identifying the intervals during a given satellite pass ($k = 1, 2, \ldots, KM-1$).
J		Numbering integer for fiducial times, i.e., the number of 2-minute intervals between first fiducial interrupt and previous GMT midnight.
L_o	WAVE	Vacuum wavelength associated with the frequency $\overline{f}_o$. $(L_o = \frac{c}{f_o})$
n	XNDT	Mean motion of satellite ($n = \frac{2\pi}{T}$).
M(t)	XMK	Mean anomaly of satellite.
N_k	DOP(K)	Cycle (doppler) count during kth interval.
R_k	REF(K)	Refraction correction count during kth interval.
R_o		Radius of the earth.
S_k		Theoretical slant range difference for kth interval.
$\hat{S}_{ko}$		Measured slant range difference for kth interval.
T		Orbital period of the satellite.
T_c	ETIM	Reading of navigator's clock (GMT) at first fiducial interrupt.
t_o		Time corresponding to the first fiducial time interrupt from ephemeral data.

Term or Symbol	Fortran Name	Meaning
t_f	STIM+4	Time at which navigator's position is computed (time of fix).
t_p	TP	Time of satellite perigee (GMT).
Δt_p	T	Time between satellite perigee and first fiducial interrupt.
u, v, w		Coordinate system fixed with respect to satellite orbit ellipse.
V		Navigator's speed at estimated first fiducial time.
X, Y, Z		Coordinate system fixed with respect to inertial space.
x, y, z		Coordinate system fixed with respect to the rotating earth.
x', y', z'		Coordinate system of satellite with respect to inertial space.
β	B	Angle between right ascension of ascending node and right ascension of Greenwich.
φ_e	ELAT	Navigator's estimate of his latitude.
φ_{fix}	FLAT	True geodetic latitude coordinate of the navigator at time of fix.
φ_k		Navigator's geodetic latitude at end of interval k.
Δ_φ		Improvement to geodetic latitude resulting from navigation equations.
ω	SOME	Argument of perigee of satellite orbit.
$\dot{\omega}$	SOMD	Rate of change of argument of perigee.

Term or Symbol	Fortran Name	Meaning
i		Angle of inclination of orbit plane with respect to equatorial plane.
λ_e	ELON	Navigator's estimate of his longitude.
λ_{fix}	FLON	True geodetic longitude coordinate of the navigator at time of fix.
λ_k		Navigator's geodetic longitude at end of interval k.
Δ_λ		Improvement to geodetic longitude resulting from navigation equations.
Λ_G	XLMG	Right ascension of Greenwich at time of satellite perigee (i. e., hour angle of Greenwich).
Ω	COME	Right ascension of ascending node.
$\dot{\Omega}$	COMD	Rate of change of right ascension of ascending node.
X_{sk}, Y_{sk}, Z_{sk}	XS, YS, ZS	Satellite coordinates in X, Y, Z system at interval k.
X_{nk}, Y_{nk}, Z_{nk}	XN, YN, ZN	Navigator's coordinates in X, Y, Z system at interval k.
η_k	DN(K)	Incremental out-of-plane (cross plane) component of satellite.
$\Delta\bar{f}$		Improvement to offset frequency resulting from navigation equations.
ω_e	OMGE	Rotational rate of the earth.
f		Flattening of the reference ellipsoid.
PDAY	PDAY	Day (GMT) of first fiducial interrupt.
TPDAY	TPDAY	Day (GMT) of satellite perigee (t_p).
T_o	STIM	Time (GMT) of first fiducial interrupt (i. e., corrected value of T_c).

Appendix G

NONSTANDARD NUMERICAL COMPUTATION ROUTINES

In order to write a digital computer program to implement the navigation solution computations and alert computations provided in this document, several special numerical routines other than those available in a standard computer command repertoire must be written. These special routines are:

a. Sine,

b. Cosine,

c. Square root,

d. Arc sine,

e. Arc cosine, and

f. Arc tangent.

This Appendix will provide information which will allow implementation of these routines using standard computer instructions of add, multiply, and divide.

SINE, COSINE

The algorithm given here determines $Y = \sin \frac{\pi}{2} X$ for $-1 < X < +1$. The algorithm given is that given on page 140 of Ref. 16. The $\cos \frac{\pi}{2} X$ is determined by use of the equation,

$$\cos \frac{\pi}{2} X = \sin \frac{\pi}{2} (1 - X) .$$

In consideration of the above, the theoretical error is only discussed in terms of the sine function.

The algorithm to be used in the solution for $\sin\frac{\pi}{2}X$ is the Hastings polynomial approximation for the sine function,

$$\sin\frac{\pi}{2}X = \sum_{i=0}^{4} C_{2i+1} X^{2i+1} ,$$

where

$$C_1 = 1.570 \quad 796 \quad 318 \quad 47$$

$$C_3 = -0.645 \quad 963 \quad 711 \quad 06$$

$$C_5 = 0.079 \quad 689 \quad 679 \quad 28$$

$$C_7 = -0.004 \quad 673 \quad 765 \quad 27$$

$$C_9 \quad 0.000 \quad 151 \quad 484 \quad 19$$

$$\sum_{i=0}^{4} C_{2i+1} = 1.000 \quad 000 \quad 005 \quad 31 .$$

As can be seen by the value of $\sum_{i=0}^{4} C_{2i+1}$ in the above table, the error in sin y at $y = \frac{\pi}{2}$ for the Hastings approximation is 5×10^{-9} if all coefficients can be used as given. However, since a minimum word length of 37 bits would be necessary to achieve this minimum error, the error presently achieved with a 30-bit computer would provide a more realistic error. For a 30-bit computer the coefficients can be expressed such that

$$\sum_{i=0}^{4} C_{2i+1} = 0.000 \quad 000 \quad 011$$

giving an expected error of 1.1×10^{-8}. This error is within the required accuracy for the computations required by this document.

ARC SINE, ARC COSINE

The algorithm given here determines $Y = \sin^{-1}(X)$ for $0 \le X \le 1$. The algorithm is that given in Ref. 16 on page 163. The arc cosine is determined by

$$\cos^{-1} X = \frac{\pi}{2} - \sin^{-1} X .$$

The algorithm to be used in the solution for $\sin^{-1} X$ is the Hastings polynomial approximation for the arc sine function,

$$\text{arc sin } X = \frac{\pi}{2} - \sqrt{1 - X}\ \psi(X) ,$$

where

$$\psi(X) = a_o + a_1 X + a_2 X^2 + a_3 X^3 \cdot \ldots\ldots + a_7 X^7$$

$$a_0 = 1.5707\ 963\ 050$$

$$a_1 = -0.2145\ 988\ 016$$

$$a_2 = 0.0889\ 789\ 874$$

$$a_3 = -0.0501\ 743\ 046$$

$$a_4 = 0.0308\ 918\ 810$$

$$a_5 = -0.0170\ 881\ 256$$

$$a_6 = 0.0066\ 700\ 901$$

$$a_7 = -0.0012\ 624\ 911 .$$

ARC TANGENT

The algorithm given here determines $Y = \tan^{-1}(X)$ for $-1 \le X \le 1$. The algorithm is that given in Ref. 16 on page 134. The algorithm is the Hastings polynomial approximation for the arc tangent function,

$$\arctan X = \sum_{i=0}^{4} C_{2i+1} X^{2i+1} ,$$

where

$$C_1 = 0.999\ 8660$$
$$C_3 = -0.330\ 2995$$
$$C_5 = 0.180\ 1410$$
$$C_7 = -0.085\ 1330$$
$$C_9 = 0.020\ 8351$$

SQUARE ROOT

The algorithm given here determines $Y = \sqrt{X}$ for all ranges of X. The algorithm to be solved is given as follows:

a. Compute an initial approximation to $\sqrt{X}$ as:

$$A_o = \frac{X}{2} + \frac{1}{2} .$$

b. Then compute by Newton's method

$$A_1 = \left(\frac{X}{A_o} + A_o\right) \cdot \frac{1}{2}$$

$$A_2 = \left(\frac{X}{A_1} + A_1 \right) \cdot \frac{1}{2}$$

$$A_3 = \left(\frac{X}{A_2} + A_2 \right) \cdot \frac{1}{2} .$$

c. Then $Y = \sqrt{X} = A_3$.